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JOURNAL
OF
THE ROYAL SOCIETY
OF
WESTERN AUSTRALIA, INC.

Founded 1913 :: :: Incorporated 1937

Vol. XXVIII
1941 - 1942



The Authors of Papers are alone responsible for the statements
and
the opinions expressed therein.

Published 22nd May, 1944.

Printed for the Society by
ROBERT H. MILLER, Government Printer, Perth.

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THE ROYAL SOCIETY OF WESTERN AUSTRALIA, INC.

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CONTENTS.

VOLUME XXVIII.

	Page
	ii.
Office Bearers	...
Annual Report	...
Treasurer's Report	...
Proceedings—Abstract of	...
Index of Authors	...
General Index	lxxxix.

Presidential Address—The Vegetation of Western Australia by C. A. Gardner	xi.
1. Permian Productinae and Strophalosiinae of Western Australia. By K. L. Pren- dergast	1
2. The Occurrence of the Genus <i>Conoclypus</i> in the North-West Division, Western Australia. By Irene Crespin	75
3. Fibroferrite and Copiapite from Yetar Spring near Chidlows. By R. T. Prider	79
4. The Geology and Petrology of part of the Toodyay District, Western Australia. By R. T. Prider	83
5. Revision of the Embioptera of Western Australia. By Consett Davis	139
6. Ecological Succession observed during Regeneration of <i>Triodia pungens</i> , R. Br. after burning. By Nancy T. Burbidge	149
7. Ecological Notes on the Vegetation of the 80-mile Beach. By Nancy T. Burbidge	157
8. Bryozoa from the Wandagee and Nooncanbah Series (Permian of Western Australia)—Part I. By Joan M. Crockford	165
9. A Revision of some previously described species of Bryozoa from the Upper Palaeozoic of Western Australia. By Joan M. Crockford	187
10. Fossil Plants from Gingin, Western Australia. By A. B. Walkom	201
11. Marine Copepods from Western Australia (Series II.). By W. S. Fairbridge	209
12. A Consideration of the Insect Population associated with Cow Dung at Crawley, W.A. By G. J. Snowball	219
13. The Essential Oils of the Western Australian Eucalypts. By E. M. Watson	247

The Royal Society of Western Australia (Inc.).

ANNUAL REPORT OF THE COUNCIL FOR THE YEAR ENDING 30th JUNE, 1942.

Ladies and Gentlemen,

Your Council begs to submit the following report for the year ended 30th June, 1942.

Council.—As in the past several years an Executive Committee was appointed to deal with the routine business of the Society and to report quarterly to the Council. The Council met on six occasions and the Executive Committee on six occasions during the year.

Finance.—The General Fund shows a balance of £146/1/5 and the Endowment Fund now amounts to £271. There are certain commitments to the Government Printer against the General Fund in connection with the publication of Volume 27, which has not yet been completed.

Membership.—Membership remains almost the same as at the commencement of the year. Members elected during the year include one Corresponding member, eight ordinary members and two associates, while two associates have transferred to full membership. Six ordinary members have resigned during the year.

We regret to record the loss by death of four of our members—Mr. W. E. Shelton, Drs. W. E. Blackall and H. J. Lotz and the Hon. John Nicholson. All of these gentlemen took a keen personal interest in the proceedings of the Society. Mr. Shelton was at various times president, librarian and secretary of this Society. The Hon. John Nicholson acted for some years as a member of the Endowment Lands Committee and rendered the Society considerable assistance at the time of its incorporation.

There are at present 150 members of the Society made up as follows:—

Honorary members	7
Corresponding members	9
Life member	1
Ordinary members	98
Associate members	35

Journal.—Volume 27 is nearing completion, and a number of the papers for the succeeding volume, No. 28, are in course of publication. During the past year fourteen papers were presented to the Society for publication in the Journal.

Mr. Southern is relinquishing the office of Editor after twelve years' service in this capacity. The Council wishes to record its appreciation of Mr. Southern's excellent work in connection with the publication of the Journal during this period. Mrs. Jenkins is undertaking the duties of editor.

Library.--The Society has now entered into exchange of publications with a total of 189 institutions, of which 56 are in Australia, 16 in the United Kingdom, 23 in other parts of the British Empire, 48 in North and South America, 42 in Europe and four in Asia. Many exchange publications are coming to hand fairly regularly, but in some instances overseas institutions are holding their publications in reserve to be forwarded after the war. The Council of this Society has decided, in view of the danger of loss during transit, to hold copies of the Journal which would normally be forwarded to overseas exchanges and to forward them in more peaceful times.

The Council wishes to express its thanks to Mr. A. Gibb Maitland for further donations to the Society's library made during the year.

C. A. GARDNER,
President.

REX. T. PRIDER,
C. F. H. JENKINS,
Joint Hon. Secretaries.

THE ROYAL SOCIETY OF WESTERN AUSTRALIA, INCORPORATED.
Statement of Receipts and Expenditure for the Year ended 30th June, 1942.

Balance Sheet as at 30th June, 1942.

Liabilities.		Assets.	
Subscriptions Paid in Advance	£ s. d.	Cash at Bank—	£ s. d.
Amounts Owing—Rent	...	General Fund	...
Investment—Life Membership Fund	...	Medal Fund	...
Surplus of Assets over Liabilities	...	Endowment Fund	...
	531 18 9		...
		Subscriptions in Arrears	...
		Authors' Reprints and Half Cost of Books—Outstanding	...
		Investments—	...
		War Savings Certificates at Valuation	...
		1956 War Loan	...
		Fixed Deposit at Commonwealth Bank	...
		Library Shelving at Cost	...
	£560 10 3		£560 10 3

Note.—£18 placed on fixed deposit at the Commonwealth Bank, Perth, on 30th April, 1942, for one year at 1 $\frac{3}{4}$ per cent. per annum.

Audited and found in agreement with books, receipts, and vouchers produced. We consider this to be a true statement of the Royal Society's Accounts.

L. J. H. TEAKLE, Hon. Treasurer,
1st July, 1942.

J. SHEARER,
H. P. ROCKETT,
Hon. Auditors.

8/7/1942.

ABSTRACT OF PROCEEDINGS, 1941-1942

8TH JULY, 1941—

Annual General Meeting in Gledden Hall. Presidential Address: "Developments in Optical Science," by Professor A. D. Ross, M.A., D.Sc.

Royal Society's Medal—Presentation of the Royal Society's Medal by His Excellency the Lieutenant Governor, Sir James Mitchell, K.C.M.G., to Professor E. de C. Clarke, M.A.

12TH AUGUST, 1941—

Paper—“The Petrology of Part of the Toodyay District,” by Dr. R. T. Prider.

Talk—“Detection of Forest Fires,” by Mr. A. C. Shedly, M.Sc.

9TH SEPTEMBER, 1941—

Paper—“The Occurrence of the Genus *Conoclypus* in the North-West Division, Western Australia,” by Irene Crespin, B.A., communicated by Professor E. de C. Clarke, M.A.

Talk—“Insects and War,” by Mr. C. F. H. Jenkins, M.A.

Exhibits—Dr. R. T. Prider exhibited specimens of gypsum crystals collected from the walls and roofs of old workings at Oroya North Blocks and Paringa Mines, Kalgoorlie.

14TH OCTOBER, 1941—

Paper—“Fibroferrite and Copiapite from Yetar Spring,” by Dr. R. T. Prider.

Talk—“How the Flour Mill Works,” by Dr. L. W. Samuel.

11TH NOVEMBER, 1941—

Talk—“Copper Deficiency Diseases in animals in the South-West,” by Dr. H. W. Bennetts.

Exhibits—Mr. L. Glauert exhibited portions of a skull of the extinct marsupial, *Diprotodon*. The specimen was collected by Mr. L. L. Miller, of Warrawagine Station, Oakover River.

9TH DECEMBER, 1941—

Papers—“Regeneration of *Triodia pungens*, R.Br. after burning with special reference to ecological succession,” by Nancy Burbidge, B.Sc. (Hon.).

“Revision of the Embioptera of Western Australia,” by Mr. Consett Davis, M.Sc., communicated by Mr. L. Glauert, B.A.

10TH MARCH, 1942—

Papers—“Ecological Notes on the De Grey-Coongan Area with special reference to Physiography,” by Nancy Burbidge, B.Sc. (Hon.).

“Ecological Notes on the Vegetation of the 80-mile beach,” by Nancy Burbidge, B.Sc. (Hon.).

Talk—“W.A. Stone Implements,” by Mr. H. V. V. Noone, M.R.A.I., M.R.A.S.

Exhibits—Mr. A. Gibb Maitland exhibited some fine examples of New Guinea stone implements and drew attention to the different type of workmanship compared with the exhibits illustrating Mr. Noone's address.

14TH APRIL, 1942—

Papers—“Bryozoa from the Wandagee and Nooncanbah series of Western Australia,” Part I, by Joan Crockford, M.Sc., communicated by Professor E. de C. Clarke, M.A.

“A Revision of some previously described species of Bryozoa from the Upper Palaeozoic of Western Australia,” by Joan Crockford, M.Sc., communicated by Professor E. de C. Clarke, M.A.

“Fossil Plants from Gingin, Western Australia,” by Dr. A. B. Walkom, communicated by Professor E. de C. Clarke, M.A.

“Two New Copepods from Western Australia,” by Mr. W. S. Fairbridge, B.Sc.

12TH MAY, 1942—

Papers—“Metamorphosis of the Jasper Bars of Western Australia,” by Dr. K. R. Miles.

Exhibits—Dr. R. T. Prider exhibited an example of Banded Quartz Hypersilene Rock from 12 miles north-west of Bolgart.

9TH JUNE, 1942—

Papers—“A consideration of the Insect Population associated with Cow Dung at Crawley, W.A.,” by Mr. G. J. Snowball, B.Sc. (Hon.).

“The Essential Oil of *Eucalyptus erythronema*” by Dr. E. M. Watson.

Exhibits—Mr. R. C. Wilson exhibited specimens of copper from Marda as an example of the good results obtained by the use of small smelting plants.

INDEX OF AUTHORS.

Burbridge, N.	...	...	...	...	...	...	149, 157
Crespin, L.	...	...	...	...	...	...	75
Davis, C.	...	...	...	...	...	...	139
Fairbridge, W. S.	...	...	...	...	...	...	209
Gardner, C. A.	...	...	...	...	...	...	xi
Prendergast, K. L.	...	...	...	...	...	...	1
Prider, R. T.	...	...	...	...	...	...	79, 83
Crockford, J.	...	...	...	...	...	...	165, 187
Snowball, G. J.	...	...	...	...	...	...	219
Walkom, A. B.	...	...	...	...	...	...	201
Watson, E. M.	...	...	...	...	...	...	247

I.—THE VEGETATION OF WESTERN AUSTRALIA.

WITH SPECIAL REFERENCE TO THE CLIMATE AND SOILS.

PRESIDENTIAL ADDRESS, 1942.

BY CHARLES AUSTIN GARDNER.

Read 13th July, 1942; published 28th March, 1944.

CONTENTS.

	Page
I. Introduction	xii.
II. The Elements of the Australian Flora	xiii.
1. The Antarctic Element	xv.
2. The Palaeotropic Element	xx.
3. The Australian Element	xxiii.
III. Physiography	xxvii.
IV. Geology and Soils	xxix.
V. Climate	xxx.
1. The Climatic Cycle	xxx.
2. Temperature	xxxiii.
3. Humidity, Evaporation and Wind	xxxiv.
4. Ratio of Precipitation to Evaporation	xxxiv.
VI. Relationships between the Climate and Vegetation of Western Australia	xxxv.
VII. The Provinces and their Formations	xxxviii.
1. The Northern Province	xxxviii.
2. The South-West Province	xli.
(a) The Forest Formations	xlii.
(i) The Jarrah Forest	xlii.
(ii) The Karri Forest	xliii.
(iii) The Tuart Forest	xliii.
(b) The Woodland Formations	xliv.
(i) Temperate Savannah Woodland	xliv.
(ii) The Sclerophyllous Woodland	xliv.
(c) Lateritic Formations	xlvi.
(d) Formations of the Granite Rocks	xlvi.
(e) Swamp Formations	xlvii.
(f) Halophytic and Dune Formations	xlviii.
(g) Sand-heaths	xlviii.
3. The Eremean Province	l.
The Formations	li.
(a) Sclerophyllous Woodland	li.
(b) Salsolaceous Shrub Steppe	li.
(c) Mulga Bush	li.
(d) Halophytic Formations	liv.
(e) The Triodia Steppe	lv.
(f) The Desert	lvi.

VIII. Epharmosis and Growth-forms	...	...	...	...	...	lvii.
1. Trees and Shrubs	...	...	...	...	...	lviii.
2. Lianes	...	...	...	...	...	lx.
3. Herbs	...	...	...	...	...	lxii.
IX. Climatic Tables—						
Table I.—Mean Monthly and Annual Precipitation in Points (100 points = one inch)	...	...	...	...	...	lxvi.
Table II.—Annual and Seasonal Rainfall Tables, showing Rainfall for the four consecutive wettest months, the four consecutive driest months, the percentage of the four wettest months, and the Annual Rainfall Variation ex- pressed as a percentage of the annual rainfall	...	...	...	...	...	lxix.
Table III.—Relative Humidity—Mean Monthly Readings for 9·0 a.m. and 3·0 p.m.	...	...	...	...	...	lxxii.
Table IV.—Saturation Deficit—Mean Monthly Averages for 9·0 a.m.	...	...	...	...	...	lxxiii.
Table V.—Climatic Statistics of Rainfall and Temperature, Saturation Deficit, etc.	...	...	...	...	...	lxxv.
X. Maps—						
Plate I.—Summer Rainfall—November to April—Isohyets in inches)	...	...	...	...	...	lxxvi.
Plate II.—Winter Rainfall—May to October—(Isohyets in inches)	...	...	...	...	...	lxxvii.
Plate III.—Normal Mean Temperature—Isotherms in ° F. for January	...	...	...	...	...	lxxviii.
Plate IV.—Normal Mean Temperature—Isotherms in ° F. for July	...	...	...	...	...	lxxix.
Plate V.—Rainfall Variability—Variation from the Mean, expressed as per cent.	...	...	...	...	...	lxxx.
Plate VI.—The Meyer Ratio	...	...	...	...	...	lxxxi.
Plate VII.—The $\frac{\text{Seasonal Precipitation}}{\text{Seasonal Saturation Deficit}}$ Ratio	...	...	...	...	...	lxxxii.
Plate VIII.—The $\frac{\text{Seasonal Precipitation}}{\text{Seasonal Temperature}}$ Ratio	...	...	...	...	...	lxxxiii.
Plate IX.—The Three Provinces of Vegetation and Climate	...	...	...	...	...	lxxxv.
Plate X.—The Phytogeographical Formations	...	...	...	...	...	lxxxvii.

I. INTRODUCTION.

The geographical distribution of plants and the study of plant habitats is one of the most interesting aspects of modern botany, and of the countries of the world, few are more favourably situated for this study and its bearing on questions of evolutionary history than Western Australia. In few countries has the ecological aspect been of such general application for, in the general mosaic of its soil types, the use of plants as indicators of the soil has been recognised from the earliest days of our history as criteria in the selection of land for agricultural purposes.

In a young country such as Western Australia, there are many opportunities for the botanist and, although botanical investigation of necessity rests on the foundation of systematic work conducted in the arid environment of the herbarium, there are many vital problems which can be solved only in the more inspiring atmosphere of the field. Given this necessary systematic basis, many are the avenues of approach which are opened up for scientific research which, because of the almost virgin condition of so much of the terrain, offer possibilities denied to workers in the less fortunate older lands.

Phytogeographical research in Western Australia may be said to have commenced with the publication of Diels' *Die Pflanzenwelt von West-Australien* (1906). The foundations, however, were laid down by Sir Joseph Dalton Hooker in 1859, by the publication of his classic *Introduction to the Flora of Tasmania*, in which he propounded certain theories regarding the origin and affinities of the Australian flora, and gave floristic analyses which are invaluable for students today. Diels, who visited Western Australia in 1901 and 1902, dealt only with the vegetation of temperate Western Australia. It must be remembered, however, that at this time, means of transport were not what they are today, and it is surprising that he accomplished so much in so short a space of time. The work is, however, an indispensable one for all students of the plant geography of South-Western Australia.

For over a century, in fact from the time when Dampier visited these shores, the flora of Australia has claimed the attention of botanists throughout the world. This is due to the fact that this flora, as a separate geographical entity, ranks high amongst those floras which are remarkable for the high degree of endemism amongst their species. Only in South Africa, especially in the Cape Peninsula, and in South America, do we find anything comparable in the number of autochthonous species so rich in vegetative and floristic forms. The Cape Peninsula and South-Western Australia afford interesting examples for comparison.

It is not that the families comprising the Australian flora are in themselves endemic. Far otherwise: out of the total number of these there are but three families which are strictly endemic in Australia, with a total number of less than 30 species. Rather is it the number of endemic genera and species, which is surprisingly large in some areas (especially in the South-West of Australia), making up as much as 75 per cent. of the total species. There are a number of families and groups, on the other hand, which are mainly Australian, that is, the greater number of genera and species are endemic here, but some of the genera and species also occur in other lands, or, there are conjunctive genera and species present in these remote areas. These furnish important evidence, for they stand today as indisputable proof that these widely dispersed areas had at one time a close relationship, if not a common origin. The presence of these groups and species in countries like America and Africa, explain two important facts: (a) that the Australian continent was not always isolated, and that (b) the isolation has been of sufficient duration to enable the distinctive elements of the Australian flora to make a peaceful and progressive evolution free from any external influences, resulting in a specialised flora with a degree of endemism rare in other continents.

II. THE ELEMENTS OF THE AUSTRALIAN FLORA.

The geographical isolation of the Australian continent, its uniform topography, and the resultant gradation of climatic areas which range from tropical to temperate, are the main considerations which must be borne in mind when we approach the study of the vegetation of Western Australia. Separated

from the rest of the world by the wide expanses of the Pacific, Indian, and Southern oceans, the only geographical approach for terrestrial plants is by way of Malaya and New Guinea, a line of communication which is interrupted by the barrier of the Timor and Arafura seas, and the still more restricted barrier of the Torres Strait. Australia is, therefore, of all the great land masses of the earth, the most isolated, and it is this isolation that accounts for its peculiar flora and fauna.

That this isolation did not always exist is evidenced by certain relationships with the vegetation of lands now far removed, such as South America, South Africa, Malaya, and Madagascar. These relationships are exhibited by those families and groups which are more or less common to two or more of these areas. There are certain large families, such as the Compositae, Gramineae, and Cyperaceae, which have a more or less cosmopolitan distribution but, on the other hand, it is amongst the more restricted groups, most highly developed in Australia—but with relationships with other countries through conjunctive genera—that these relationships are most clearly exhibited. To give a general indication of these relationships we may take, by way of example, the ancient group Gymnospermae. Here we find *Araucaria* linking South America with Australia by way of New Zealand and New Caledonia; *Callitris* and *Actinostrobus* of Australia have their counterpart in the African genus *Widdringtonia*; while in Cycas there is a link with Asia, and a secondary link through *Macrozamia* with the African *Encephalartos*. But when we consider such families as Proteaceae, Euphorbiaceae, Restionaceae, Goodeniaceae, and Stylidiaceae, we find these relationships even more closely expressed, both through the general limits of areas of distribution, and through conjunctive genera, and even species.

While today, in the present stage of our knowledge, it is almost impossible to attempt to explain the *origin* of the Australian flora, a floristic analysis of this flora shows us that it has much in common with the floras of the lands referred to, and thus we are forced to suppose that there existed some former land communications between Australia, South America, and South Africa. Whether the groups which today are predominantly Australian and have spread through the channels of communication suggested, or whether they are migrants which have become more abundant and diversified here than in their original home, is a question that may some day be answered by palaeobotanists, but not by present day development.

Whatever may be said of the origin of the Australian flora, we must recognise the fact that certain elements have been instrumental in its evolution. These elements appear to have been recruited from two or three principal sources: an ancient Antarctic or Subantarctic Element, derived from a southern source, and exhibited by the existing relationships between the floras of Australia, New Zealand, Southern (principally Andean) South America, and South Africa; and a more recent (?) Palaeotropic Element which has migrated to Australia by way of India, Malaya, and Melanesia.

Diels postulates a third element—the Australian Element, but an analysis of this clearly indicates that this so-called Australian Element is in reality a secondary element at the most, for it appears to have too much in common with both the Antarctic and Palaeotropic elements to be considered in itself a true element. In his definition of the Australian Element, Diels states: “The Australian Element comprises numerically the majority of the plant species occurring in Australia. Its groups and genera occur either only in Australia, and have no near relations outside the continent, or they possess

a few wandering representatives which are evidently very closely connected with the main Australian stock." He then enumerates those groups which contain, *inter alia*, the following families:—

Centrolepidaceac	Restionaceae
Philydraceac	Santalaceae
Proteaceae	Phytolaccaceae
Pittosporaceae	Tremandraceae
Stackhousiaceae	Halorrhagaceae
Epacridaceae	Myoporaceae
Goodeniaceae	Styliadiaceae

He omits Byblidaceae and Cephalotaceae, which at the time of his work were not recognised as distinct families, but apart from these, the only *endemic family* is the Tremandraceae.

In addition, he enumerates several groups and certain genera, amongst which are: Haemodoraceae-Conostylidace; Leguminosae-Podalyriace-Genistcae; Acacia; Rutaceae-Boroniace; Euphorbiaceae-*Stenolobae*; Dodonaea; Rhamnaceae-Rhamneac; Sterculiaceae-Buttnerieac-*Lasiopetalae*; Myrtaceae-Leptospermcae-*Chamaelaucieae*. The names in italics (mine) are those of groups which are strictly endemic. Examples of some of these will be discussed in greater detail.

1. THE ANTARCTIC ELEMENT.

Both Hooker and Diels claimed for the Antarctic Element those plants which were common to South-Eastern Australia, New Zealand, Tierra del Fuego, and Andean Patagonia. This is indeed a very restricted area of distribution, and the number of conjunctive genera is very small. Typical of the element in this restricted sense is *Nothofagus*. Taking this limited view of the Antarctic Element, there are, beyond a few genera such as *Centrolepis*, *Trichocline*, and one or two others, no representatives of the Antarctic Element in Western Australia. The Antarctic Element has received a wider treatment from both Field Marshall Smuts and Sir Arthur Hill, who claim for the element "those plants which have originated from the ancient lands of the Southern Hemisphere, as against those which have migrated from the north." Under this definition we can recognise certain larger groups which are confined generally to the southern lands, such as temperate Australia, New Zealand, South America, and South Africa, and this broader conception of the Antarctic Element reduces considerably the importance of the Australian Element in the sense employed by Diels. Therefore, leaving aside the more restricted representatives of the Antarctic Element in its narrower sense, we have to recognise a number of families and genera which have a common southern distribution: an element either restricted to the southern lands, or most highly developed there, with occasional representatives which have undergone a northern migration under conditions which favour their spread. Such are the migrations of *Protea* into Abyssinia through the highlands, and of *Baeckea* and *Haemodorum* into eastern Asia, or of *Dracophyllum* into northern Queensland. Conversely, we may consider the southern migration of *Rhododendron* in high altitudes into the Bellenden-Kerr mountains in Queensland.

While it is obviously impossible to deal comprehensively with all the groups which comprise the Antarctic Element, a consideration of some of the more important will illustrate the general distribution of those which are included in it. In the following tables the numbers in brackets refer to the

number of species ; names indicated by asterisks are those of genera not represented in Western Australia :—

	(a) Restionaceae.
<i>Anarthria</i>	(6) S.W. Australia
<i>Ecdeiocolea</i>	(2) S.W. Australia
<i>Hopkinsia</i>	(1) S.W. Australia
<i>Lyginia</i>	(2) S.W. Australia
<i>Phyllocomus*</i>	(1) South Africa
<i>Loxocarya</i>	(8) S.W. Australia
<i>Onychosepalum</i>	(1) S.W. Australia
<i>Chondropetalum*</i>	South Africa
<i>Lepyrodia</i>	(7) Southern Austr. and N. Zeal.
<i>Ascidosperma*</i>	(1) South Africa
<i>Diclsia</i>	(1) S.W. Australia
<i>Restio</i>	(110) Mainly S. Africa, a few temp. Austr.
<i>Leptocarpus</i>	(12) temp. Austr., Cochin China, and Chile
<i>Elegia*</i>	(20) S. Africa
<i>Lepidobolus</i>	(3) Southern Austr.
<i>Calopsis*</i>	(10) S. Africa
<i>Cannomois*</i>	(8) S. Africa
<i>Lamprocaulos*</i>	(2) S. Africa
<i>Chaetanthus</i>	(1) S.W. Austr.
<i>Thamnochortus*</i>	(25) S. Africa
<i>Staberoha*</i>	(6) S. Africa
<i>Hypolaena</i>	(2) Southern Austr.
<i>Calorophus</i>	(3) Southern Austr. and N. Zeal.
<i>Anthochortus*</i>	South Africa.
<i>Mastersiella*</i>	(10) South Africa
<i>Loxocarya</i>	(8) S.W. Austr.
<i>Harperia</i>	(1) S.W. Austr.
<i>Hypodiscus*</i>	(15) South Africa
<i>Wildenowia*</i>	(15) South Africa

Summary.

- 13 genera endemic in South Africa.
- 10 genera endemic in South-Western Australia.
- 2 genera common to temperate Australia.
- 2 genera common to temperate Australia and New Zealand.
- 1 genus common to South Africa and temperate Australia.
- 1 genus common to Chile, Southern Australia, and Cochin China.

—

(b) Centrolepidaceae.

<i>Gaimardia*</i>	(3) temp. S. America, N. Zeal., and Austr.
<i>Alepyrum*</i>	(2) temp. S. America, N. Zeal., and Austr.
<i>Juncella</i>	(3) temp. Australia and N. Zealand
<i>Aphelia</i>	(1) temp. Australia and Tasmania
<i>Brizula</i>	(5) temp. Australia and Tasmania
<i>Centrolepis</i>	(20) temp. Australia, N. Zeal., and South America

(e) Epaeridaeae.

Sect. I.—Prionoteae—

<i>Prionotes*</i>	(1) Tasmania
<i>Lebetanthus*</i>	(1) Patagonia

Sect. II.—Epaerideae—

<i>Sprengelia*</i>	(3) S.E. Australia
<i>Andersonia</i>	(20) S.W. Australia
<i>Richea*</i>	(8) Tasmania and Victoria
<i>Dracophyllum*</i>	(11) Eastern Australia, N. Caledonia, and N. Zeal.
<i>Sphenotoma</i>	(6) S.W. Australia
<i>Cosmelia</i>	(1) S.W. Australia
<i>Lysinema</i>	(5) S.W. Australia
<i>Woolsia*</i>	(1) Eastern Australia
<i>Epacris*</i>	(30) S.E. Australia, Tasmania, N. Caled., and New Zealand
<i>Areheria*</i>	(5) Tasmania and N. Zealand

See. III.—Stypheliaeae—

<i>Styphelia</i>	(12) temp. Australia
<i>Leucopogon</i>	(140) temp. Australia (mainly S.W.), N. Zeal., and Malaya, and Pacific Islands
<i>Lissanthe*</i>	(3) S.E. Australia
<i>Cyathodes*</i>	(15) Tasmania, Victoria, N. Zeal., and Hawaiian Islands
<i>Cyathopsis*</i>	(1) New Caledonia
<i>Monotoca</i>	(7) temp. Australia
<i>Acrotriche</i>	(8) temp. Australia
<i>Coleanthera</i>	(3) S.W. Australia
<i>Brachyloma</i>	(7) temp. Australia
<i>Conostephium</i>	(5) S.W. Australia
<i>Pentachondra*</i>	(4) mountains of Tasmania and Victoria
<i>Trochocarpa</i>	(6) temp. Australia
<i>Needhamia</i>	(1) S.W. Australia
<i>Oligarrhena</i>	(1) S.W. Australia

Summary (26 genera).

- 8 South-Western Australia.
- 5 temperate Australia.
- 4 South-Eastern Australia.
- 4 Australia, N. Caled., N. Zeal.
- 2 Australia, extending to the Hawaiian Islands.
- 1 endemic in Tasmania
- 1 endemic in Patagonia.
- 1 endemic in New Caledonia.

(d) Stylidiaceae.

Subfam. Donatioideae—

<i>Donatia</i> *	(2) Antarctic S. America, New Zeal., and Tasmania
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Subfam. Stylidioideae—

<i>Plyllaehne</i> *	(4) 3 New Zeal., 1 Antarctic S. America
<i>Forstera</i> *	(4) 3 New Zeal., 1 Tasmania
<i>Oreostylidium</i> *	(1) New Zealand
<i>Levenhookia</i>	(6) 1 temp. Australia, 5 S.W. Australia
<i>Stylium</i>	(105) 96 in W. Austr. (52 endemic), 12 in Northern Australia (9 in W. Austr.), 5 common to temperate Australia, 5 endemic in S.E. Australia, 3 endemic in Indo-Malaya.

Summary (6 genera).

2 common to New Zeal. and Ant. S. America.
 1 extending to Tasmania.
 1 common to New Zealand and Tasmania.
 1 endemic in Australia.
 1 common to Australia and Indo-Malaya.

(e) Proteaceae.

Subfam. Persoonioideae—

<i>Symplyonema</i> *	(2) E. Australia
<i>Bellendena</i> *	(1) Tasmania
<i>Agastachya</i> *	(1) Tasmania
<i>Beauprea</i> *	(7) New Caledonia
<i>Dilobeia</i> *	(1) Madagascar
<i>Cenarrhenes</i> *	(1) Tasmania
<i>Garnieria</i> *	(1) New Caledonia
<i>Persoonia</i>	(62) Australia and New Zealand
<i>Brabeium</i> *	(1) South. Africa

Subfam. Proteeae—

<i>Aularx</i> *	(3) S. Africa
<i>Leucadendron</i> *	(70) S. Africa
<i>Protea</i> *	(75) S. and trop. Afr.
<i>Leucospermum</i> *	(40) S. Africa
<i>Faurea</i> *	(10) Africa and Madagasc.
<i>Serruria</i> *	(50) S. Africa
<i>Mimetes</i> *	(15) S. Africa
<i>Sorocephalus</i> *	(10) S. Africa
<i>Paranomus</i> *	(12) S. Africa
<i>Orothamnus</i> *	S. Africa
<i>Diastella</i> *	S. Africa
<i>Spatalla</i> *	(25) S. Africa
<i>Spatalopisis</i> *	(5) S. Africa
<i>Petrophila</i>	(35) Austr. (W.A.)
<i>Isopogon</i>	(30) Austr. (W.A.)
<i>Adenanthes</i>	(20) S.W. Austr.
<i>Stirlingia</i>	(5) S.W. Austr.
<i>Synaphea</i>	(8) S.W. Austr.
<i>Conospermum</i>	(35) Australia
<i>Franklandia</i>	(2) S.W. Austr.

Subfam. Grevilleoideae—

<i>Darlingia</i> *	(1) E. Austr.
<i>Buckinghamia</i> *	(1) E. Austr.
<i>Grevillea</i>	(180) Austr.
<i>Strangea</i>	(3) Austr.
<i>Carnarvonia</i> *	(1) E. Austr.
<i>Hakea</i>	(100) Austr.
<i>Orites</i> *	(6) E. Austr.
<i>Helicea</i> *	(40) Japan, Indo-Malaya, E. Austr.
<i>Xylomelum</i>	(4) Austr.
<i>Lambertia</i>	(8) Austr.
<i>Roupala</i> *	(40) South America and New Caledonia
<i>Panopsis</i> *	(8) trop. America
<i>Macadamia</i> *	(5) E. Austr.
<i>Hicksbeachia</i> *	(1) E. Austr.
<i>Kermadecia</i> *	(5) E. Austr. and New Caledonia
<i>Grevina</i> *	(1) Chile
<i>Euplassa</i> *	(8) trop. America
<i>Embothrium</i> *	(5) Chilean Andes and E. Austr.
<i>Telopea</i> *	(3) E. Austr. and Tasmania
<i>Lomatia</i> *	(10) E. Austr., Tasmania, and Chile
<i>Knightia</i> *	(3) N. Zeal. and N. Caledonia
<i>Cardwellia</i> *	(1) E. Austr.
<i>Stenocarpus</i>	(15) N. Caledonia and trop. Austr.
<i>Banksia</i>	(50) Austr.
<i>Dryandra</i>	(52) S.W. Australia

Summary (54 genera).

- 21 genera endemic in Australia.
- 14 genera endemic in S. Africa and Madagascar.
- 3 genera endemic in America.
- 2 genera endemic in Tasmania.
- 2 genera endemic in New Caledonia.
- 1 common to S. America and N. Caledonia.
- 2 common to S. America and E. Australia.
- 2 common to New Caledonia and E. Australia.
- 1 common to Australia and New Zealand.
- 1 common to Japan, Indo-Malaya, and E. Austr.
- 1 genus endemic in Madagascar.

The preceding tables are characteristic of the groups within the Antarctic Element. They show affinities between the three great southern land masses, with Madagascar, New Caledonia, and New Zealand as intermediate points. It is interesting to find that, in general, the links between Australia and South America are usually stronger than those between Australia and South Africa. These will be referred to again under the *Australian Element*. Amongst the Restionaceae there is a high degree of endemism both in the Australian and South African groups, with one conjunctive genus for America and one for South Africa. The Centrolepidaceae are more strictly Antarctic, and the link here is between South America and Australia. The same holds good for the Epaeridaceae and Stylidiaceae, which are not represented in South Africa, the former without conjunctive genera, the latter with two. Amongst the Proteaceae however, there are powerful links with South America, in the Grevilleoideae, with two conjunctive genera ; while amongst the Proteae

the development in South Africa is even greater than in Australia, and there are again no conjunctive genera. In all cases in the Proteaceae, where a genus exists in South-Western Australia, it is more powerfully developed there than elsewhere.

At the same time, there are several genera common to both Australia and South Africa, some of which will be discussed under the Palaeotropic Element, but the following are genera confined to the countries mentioned :—

<i>Chrysithrix</i>	South Africa and S.W. Australia.
<i>Tetraria</i>	South Africa and S.W. Australia.
<i>Wurmbaea</i>	South Africa and S.W. Australia.
<i>Bulbine</i>	South Africa and temperate Australia.
<i>Caesia</i>	South Africa and temperate Australia.
<i>Podocoma</i>	Australia and America.
<i>Trichocline</i>	S.W. Australia and S. America.

These are but a few examples of the Antarctic Element, and when floral statistics have been completed for Western Australia, further additions will probably be made. Sufficient evidence has, however, been advanced to indicate the close relationships which exist between certain southern groups.

2. THE PALAEOTROPIC ELEMENT.

The Indo-Melanesian Element is expressed by those plants which are common to Australia, Indo-Malaya, and Melanesia. In Australia they are most in evidence along the Northern Australian littoral, especially in the high rainfall districts of Queensland, and extending through the rain-forest into New South Wales. The Element is also fairly well indicated in Western Australia in the Kimberley district, especially in the littoral, the riverain forest, and the monsoon woodland. The conditions governing its migration are the requirements of a megathermic flora, and, while it is most strongly represented in Western Australia in the Kimberley district, it has migrated fairly extensively along the littoral tracts. This must have taken place at a time when the climatic conditions were very different from those of to-day. The Element has not only strongly established itself in Kimberley, but its residuals may be found fairly well represented to-day in the Do Grey River district, and the Hamersley plateau. At one time it extended as far south as the South-West, for it has not only undoubtedly exerted an influence on the flora of the South-West, there are today certain representatives of this Element as far south as the karri forest. There can, indeed, be no other explanation for the occurrence of such plants as *Cartonema*, *Dioscorea*, and *Clematocissus* in regions between Geraldton and Perth. At the same time, such a direct line of communication would explain certain northern migrations of plants that are typically southern, *e.g.*, *Byblis*, certain *Droserae* and *Jacksonia*, to the tropics. Finally, if further evidence is wanted, one has but to consider the flora of the Pilbara district—the region between the De Grey and Ashburton rivers—which is today an “island” supporting the impoverished residuals of the Indo-Melanesian Element under conditions which are generally unsuitable, either as lithophytes or species of the declivities. Examples such as *Livistona*, *Astrotricha*, *Owenia*, and several herbaceous species, also the few endemics, such as *Elachnanthera*, as megathermic plants of mesophytic or hygrophytic derivation, are evidence of a former pluvial area which must have been of importance in bridging the line of communication between the north and south.

A list of the groups which comprise the Indo-Melanesian Element would be beyond the scope of this treatise. It is sufficient to state that it includes the Palaeotropic Rhizophoraceae, many Leguminosae and Gramineae, Santa-laceae, Lauraceae, Menispermaceae, Ulmaceae, Moraceae, Burseraceae, Meliaceae, Euphorbiaceae, Anacardiaceae, Celastraceae, Sapindaceae, Rhamnaceae, Malvaceae, Tiliaceae, many of the Parietales, Myrtiflorae-Myrtoideae, the Primulales, and a host of tropical Sympetalae.

While we postulate a land connection for the greater number of plants comprising the Palaeotropic Element, it must be remembered that a number have undergone an oceanic migration. Such plants as the *Rhizophoraceae*, *Terminalia*, *Carapa*, *Thespesia*, *Barringtonia*, and *Campstostemon* being examples, as well as the maritime *Spinifex* and certain dune species. They remain principally as littoral plants.

In addition to those groups or species which we regard as belonging essentially to the Palaeotropic Element, there are several groups which, while perhaps of palaeotropic origin, have become so modified, or have undergone such an extensive development, that they are no longer recognisable as typical examples. Indeed, in some instances they have assumed such importance in Australia that they have been regarded by some authors as typifying the Australian Element. I propose to consider, by way of illustration, one Order, the Leguminosae.

In the first family of this Order is the genus *Acacia*. This genus, which is represented in the tropics of both the east and west hemispheres, comprises over 500 species, of which 400 are indigenous to Australia. Of the six Sections, four are represented in Australia (all being in Western Australia), the remaining two being found in America, Africa, and Asia. The most primitive form of *Acacia* is that which possesses compound leaves. *Acacia Farnesiana*, which may be regarded as an archetype, inhabits the tropics of both the old and new worlds, extending from America, through Africa, Arabia, and India, into northern Australia. In Western Australia it extends as far south as the Murchison River, while in eastern Australia it occurs as far south as the interior of New South Wales. Within the high summer rainfall areas, e.g., in Kimberley, it is of fairly general distribution as a shrub of the savannahs, but south of the Fitzroy River it is confined to the alluvial soil of watercourses and depressions.

The remaining species of the Section Gumniferae in Australia are all endemic and of tropical distribution as far as Western Australia is concerned. *Acacia Farnesiana* alone of the Bipinnatae connects the tropical species of this genus with the temperate Bipinnatae in south-western Australia. *Acacia pulchella*, the most widespread of the latter, extends northwards to the southern limits of *Acacia Farnesiana* and southwards to the forest areas where it connects with the remainder of the species of its Section, the *Pulchellae*, which number twelve, and are of considerable importance in the high rainfall forest area of the south-west. Apart therefore, from a northern group consisting of the Gumniferae and the single representative of the Botryocephalae (*A. pachyphloia*), and a southern group in which there are 12 species of the *Pulchellae*, the two being connected by the riverain *A. Farnesiana*, there are no other leafy Acacias in Western Australia. In eastern Australia a similar development may be noted, *Acacia Farnesiana* continuing the line of development into New South Wales, while a south-eastern group (Botryocephalae) extends from the north to Victoria and South Australia.

From this original stock, a type of *Acacia* has originated which is characterised by the production of phyllodes, the leaf being represented by the simple flattened leaf-like axis of the compound leaf. Its ontogeny may be observed in any species of this type, and transitions between the two may be observed in *Acacia insolita*, a species of the eastern borders of the jarrah forest, which normally possesses both leaves and phyllodes. This large group (the Phyllodineae), numbering over 400 species, is, with the exception of a few Papuan and Pacific species, confined to Australia, the Western Australian species numbering over 300. They are found within every formation throughout the country, assuming remarkable diversity in form and varying from complete aphyll to large leaf-like phyllodes. Their highly developed floral economy, and the adaptation of a leaf-stalk or even a stem functioning as a leaf, has enabled them to withstand extreme aridity of environment, and thus they have penetrated into the arid heart of the continent, developing an epharmony which leads to complete aphyll.

While this epharmonic development is in most examples progressively manifested as we travel from wetter to drier areas, there are what appear to be retrograde divergences in some instances. For example, *Acacia alata* and *A. extensa*, both of which inhabit wet or marshy spots in the south-western forests, exhibit an apparent morphological xerophily which is misleading, for histologically *Acacia alata* at least, is a mesophyte. It lives only under conditions of shade and moisture which are the ideal conditions under which the leafy *Acacia* find their true environment; the phyllodineous species, on the other hand, have attained to their highest development under arid conditions, or at least, seasonal drought. Australia, and particularly Western Australia, is the richest in species of *Acacia* of any part of the earth, but the genus cannot be considered as belonging to any but a tropical element.

What is true of *Acacia* is apparently also true of the rest of the Mimosaceae and the Caesalpiniaceae. In this connection it is interesting to consider the range of *Albizzia*, indigenous to tropical Asia, Africa, and Australia. The Western Australian representatives are confined to the tropical north with the single exception of *Albizzia distachya*, confined to the south-west. Of the Caesalpiniaceae, both *Petalostyles* and *Labichea* are endemic in Australia, and are closely related to *Cassia*, from which they have probably been evolved; *Petalostyles* remaining megathermic, while *Labichea* extends from Queensland to south-western Australia, but without a continuous distribution between the Murchison River and the Northern Territory. *Cassia*, on the other hand, which we must regard as a tropical element, has migrated far to the south, but has not extended into the wet south-west, and its real home in Australia in the savannah and the dry interior, where, by the provision of a dense indumentum of felt or hair, it has, with practically no structural modification, penetrated to the desert.

Space does not permit me to deal at any length with the third family of the Leguminosae—the Papilionaceae, and the family is so large, and of such cosmopolitan distribution, that it is difficult to trace with any exactness its possible migrations. It is worth remembering, however, that every tribe of this important family is represented in America, which country appears to be the main centre of distribution for the family. The Dalbergieae, Sophoreae, Hedysareae, Swartzieae, Galegeae, and Phaseoleae are all most richly developed in America, five of them being found in Asia and Australia. Of the remaining five tribes, the Vicieae, Trifoleae, and Loteae are more cosmopolitan in distribution, but mainly of northern development, while in the

last two—the Genisteae and Podalyrieao—there is a marked southern development. The following list gives the distribution of these two tribes:—

Genisteae.	Podalyrieae.
South Africa 19 genera	Australia 20 genera
North Africa and Mediterranean 8 genera	North America and Siberia 3 genera
Australia 7 genera	Himalayan 2 genera
Warm regions 2 genera	Mediterranean 1 genus
Indo-Malayan 2 genera	South Africa 1 genus
N. Hemisphere (mesothermic) 1 genus	
South America 1 genus	

It is suggested that both tribes migrated southwards from the northern hemisphere, and that the Australian Podalyrieae, like the South African Genisteae, have formed their own centres of distribution. It will be noticed that the Podalyrieae are absent from both New Zealand and South America, and that both have a number of localised endemics in two centres—the Genisteae in the Cape Peninsula of South Africa, and the Podalyrieae in southern Australia.

Finally there is a relationship between the flora of Madagascar and Australia that cannot be overlooked. There is, in the first place, the remarkable distribution of the Baobab (*Adansonia*). This genus is restricted to the African savannahs, Madagascar, and that portion of Australia which lies between the Fitzroy and Victoria rivers. In the second place there are those genera which are entirely restricted to Madagascar and Australia—and particularly well developed in Western Australia—*Ruellia* and *Keraudrenia* (Sterculiaceae), and *Diplopeltis* (Sapindaceae). No attempt is made to explain this remarkable distribution.

3. THE AUSTRALIAN ELEMENT.

Botanists and zoologists have repeatedly referred to an Australian Element. Hooker, speaking of the Australian Flora, states: "It contains more genera and species peculiar to its own areas, and fewer plants belonging to other parts of the world, than any country of equal extent. About two-fifths of its genera, and upwards of seven-eights of its species are entirely confined to Australia. On the other hand, if, disregarding the peculiarities of the flora, I compare its elements with those of the floras of similarly situated large areas of land, or with that of the whole globe, I find that there is so great an agreement between these that it is impossible to regard the Australian vegetation in any other light than as forming a peculiar but not an aberrant or anomalous botanical province of the existing Vegetable Kingdom; that with only two small exceptions, the Australian families are also found in other countries; that most of those most widely diffused in Australia are such as are also the most widely distributed over the globe; and that Australia wants no known family of general distribution. That the large families and genera which, though not absolutely restricted to Australia, are there very abundant in species and rare elsewhere, and for which I shall hence adopt the term *Australian*, stand in very close relationship to groups of plants which are widely spread over the globe (as Euphorbiaceae to Ericaceae; Goodeniaceae to Campanulaceae; Stylidiaceae to Lobeliaceae; Casuarinaceae to Myricaceae). Turning again to other countries which are remarkable for the peculiarity of their vegetation,

I find that South America contains many more peculiar families than Australia, and South Africa about as many." The definition given by Diels for the Australian Element has already been quoted (p. 3), and I have already indicated that some of the groups included under his definition do not belong to this element.

On the other hand, there are certain families and groups that are either entirely Australian, or almost entirely so, with every genus represented in Australia, and but few external species. Apart from the strictly endemic groups it is difficult to define with exactitude the Australian Element, or to divorce it entirely from the Antarctic, or the Palaeotropic Element. To illustrate this difficulty we may take the sub-family *Leptospermoideae* of the Myrtaceae.

MYRTACEAE—LEPTOSPERMOIDEAE

	(a) Leptospermeae.					
<i>Osbornia</i> *	(1) N. Australia					
<i>Backhousia</i> *	(5) N. Australia					
<i>Metrosideros</i> *	(20) S. Africa, Indo-Malaya, New Zealand, Australia, Sunda Is.					
<i>Spermolepis</i> *	(2) New Caledonia					
<i>Lysicarpus</i> *	(1) N. Australia					
<i>Cloezia</i> *	(6) New Caledonia					
<i>Tepualia</i> *	(1) Chile					
<i>Syncarpia</i> *	(2) E. Australia					
<i>Xanthostemon</i>	(18) trop. Austr., N. Caled. 1					
<i>Pleurocalyptus</i> *	(1) New Caledonia					
<i>Tristania</i>	(22) Malaya, N. & E. Australia, N. Caled. 3					
<i>Angophora</i> *	(5) E. Australia					
<i>Eucalyptus</i>	(500) Australia, Malaya, Celebes, Philippines 150					
<i>Leptospermum</i>	(25) Australia, Malaya, N. Zeal. 10					
<i>Agonis</i>	(13) S.W. Australia 13					
<i>Kunzea</i>	(18) temp. Australia 12					
<i>Callistemon</i>	(12) temp. Australia 2					
<i>Melaleuca</i>	(120) Australia—one sp. extending to N. Caled., Malaya, and India 106					
<i>Lamarchea</i>	(1) S.W. Australia 1					
<i>Conothamnus</i>	(3) S.W. Australia 3					
<i>Eremaea</i>	(7) S.W. Australia 7					
<i>Phymatocarpus</i>	(2) S.W. Australia 2					
<i>Regelia</i>	(3) S.W. Australia 3					
<i>Beaufortia</i>	(15) S.W. Australia 15					
<i>Balaustion</i>	(2) S.W. Australia 2					
<i>Baeckea</i>	(60) Australia, Malaya, China 48					
<i>Astartea</i>	(5) Australia 5					
<i>Hypocalymma</i>	(18) S.W. Australia 18					

(b) Chamaelaucieae.

<i>Lhotzkyia</i>	(10) temp. Australia	....	....	....	7
<i>Calythrix</i>	(40) Australia	....	....	....	37
<i>Calythropsis</i>	(1) S.W. Australia	....	....	....	1
<i>Homalocalyx*</i>	(2) N.E. Australia				
<i>Micromyrtus</i>	(13) Australia	....	....	....	12
<i>Wehlia</i>	(5) S.W. Australia	....	....	....	5
<i>Pileanthus</i>	(3) W. Australia	....	....	....	3
<i>Chamaelaucium</i>	(12) S.W. Australia	....	....	....	12
<i>Thryptomene</i>	(22) temp. Australia	....	....	....	21
<i>Actinodium</i>	(1) S.W. Australia	....	....	....	1
<i>Darwinia</i>	(31) temp. Australia	....	....	....	27
<i>Homoranthus*</i>	(2) E. Australia				
<i>Verticordia</i>	(47) W. and N. Australia	....	....	....	47

Summary.

Sub-family Leptospermoideae	....	41 genera.
Australia	....	31 genera (15 endemic in S.W. Austr.)
Austro-Malaya, extending to India, China, New Zealand, and 1 (Metrosideros) S. Africa	....	6 genera
New Caledonia	....	3 genera
Chile	....	1 genus
Sub-family Myrtoideae	....	32 genera
America	....	22 genera (mainly S. America)
New Caledonia	....	3 genera
Indo-Malaya	....	2 genera
Malaya-Australia	....	3 genera
Australia	....	1 genus
Tropical Africa	....	1 genus
Tropics (general)	....	1 genus

In the above, and succeeding table, the first column of figures in parenthesis represents the total number of species in the genus ; the second indicates the number found in Western Australia. Names indicated by asterisks are those of genera not occurring in Western Australia.

It will be seen that of the two sub-families of the Myrtaceae, the Leptospermoideae is predominantly Australian, but that three genera are restricted to New Caledonia, while one is South American. Of the Australian genera, half are endemic in South-Western Australia. In the sub-family Myrtoideae (those with baccate fruits), the position is quite otherwise, the majority of genera being endemic in America. The Chamaelaucieae, a tribe of the Leptospermeae, is strictly Australian, and this group alone, unless we include the nine endemic genera of the Leptospermeae, can be defined as an Australian Element. The southern, or Antarctic influence is expressed by *Metrosideros* and *Tepualia*. In any case, we see once more that the Australian Element is most richly developed in South-Western Australia.

An almost parallel case is exhibited by the Goodeniaeae, but here each genus is represented in Australia:—

<i>Velleia</i>	(18) Australia	....	....	....	....	10
<i>Symphyobasis</i>	(2) Australia	....	....	....	....	2
<i>Goodenia</i>	(101) Australia	....	....	....	....	56
<i>Calogyne</i>	(5) Australia (one extending to the Philippines)	....	....	....	....	3
<i>Leschenaultia</i>	(19) Australia	....	....	....	....	17
<i>Anthotium</i>	(2) S.W. Australia					
<i>Selliera</i>	(2) One endemic in S.W. Austr., the other extending from Victoria and Tasmania to N. Zealand and Chile					1
<i>Pentaptilon</i>	(1) S.W. Australia	....	....	....	....	1
<i>Catasperma</i>	(1) N. Australia	....	....	....	....	1
<i>Diaspasis</i>	(1) S.W. Australia	....	....	....	....	1
<i>Scaevola</i>	(83) One tropics generally ; 22 Pacific and Melanesian (excl. Australia) ; Austr.					50
<i>Verreauxia</i>	(3) S.W. Australia	....	....	....	....	3
<i>Dampiera</i>	(59) Australia	....	....	....	....	48

This family represents the true Australian Element. It agrees with the definition given by Diels, for each genus is represented in Australia, only three having extraterritorial representatives. The species connecting S.E. Australia with Chile is again interesting. It will be observed that each genus is represented in Western Australia. Apart from *Selliera* and *Calogyne*, the migrant species are all species of *Scaevola*, entirely or chiefly of maritime distribution.

In addition to the three endemic families—the Tremandraceae, Byblidaceae, and Cephalotaceae, there are a number of groups with a rank less than that of family which are endemic. Examples are:—

Liliaeae-Xanthorrhoeae
Haemodoraceae-Conostylidiae
Pittosporaceae-Billardiereae
Rutaceae-Eriastemoninac-Nematolepidinae-Diplolaeninae
Euphorbiaceae-Stenolobeae
Myrtaceae-Chamaelauzieae
Verbenaceae-Chloanthoideae
Labiatae-Prostantheroideae
Compositae-Angianthinae

The number of genera is too large for inclusion here, but examples are to be found in many families. The total number has not been accurately computed.

In every case, the Australian Element is most richly developed within the South-West Province ; its real home today is the large triangular-crescentic area bordered by the coastline from Shark Bay to Israelite Bay, and extending inland to the 175 mm. (7 in.) winter isohyet. Within this area the autochthonian flora finds its highest expression in the sandy areas, either on the sand heaths, or in the sandy swamplands of the south-western littoral. While many of its groups are strictly endemic within the area, others are found in Eastern Australia, especially in Southern Queensland and South Australia, where they occur as psammophytes. They are found also in the littoral region of South Australia, where their occurrence can be explained by littoral migration, but their occurrence in southern Queensland and parts of New South Wales is more difficult of explanation.

These eastern species and groups bear the same relationship to those of South-Western Australia that the groups in South Africa and South America bear to the Australian ingredients of the Antarctic Element.

Whether South-Western Australia was the cradle of the Australian Element, or whether it is here alone that it has maintained its floristic stability, is a question which has not yet been decided. When we consider the high degree of endemism within the area, and its ecological stability, one is inclined to the former view, but, as Diels has pointed out, the occurrence of the vast epicontinental sea of Cretaceous times must have caused a division of what may originally have been an ancient pan-Australian flora, and the present distribution of such genera as *Borya*, *Petrophila*, *Isopogon*, *Grevillea*, and *Banksia*, to enumerate a few only, lends a definite support for the theory of the previous existence of a pan-Australian Element. In any case, it is in South-Western Australia alone that the true Australian flora is today most richly developed within a climatic and geologically distinct entity, in an almost perfect state of equilibrium which is disturbed only by the gradual process of climatic desiccation in operation everywhere. It is true that a disturbing influence has to some extent been at work since the advent of settlement: agriculture, with grazing, fire, and the plough, has done much to bring about important local changes in the country's physiognomy, but the work of man, and the plants which he has brought with him, including those aliens which we regard as weeds, although of great importance in man's particular economy have, in the main, proved quite ineffective as a permanent invading force when subjected to competition under natural conditions with the indigenous vegetation.

III.—PHYSIOGRAPHY.

Western Australia consists almost entirely of a low plateau with an average elevation of between 1,000 and 1,500 feet. Between Point Culver and Eyre on the south coast, between the King Leopold Range and Vansittart Bay in the Kimberley district, and in a few other places, this plateau extends to the coast. In other places, e.g., between Eyre and Eucla, and along the western coast between the Moore and Vasse rivers, the plateau descends rather abruptly to a narrow littoral plain. In the north-west, between the Murchison River and Broome, the plateau descends gradually to the coast, or the escarpment is far inland, except in the Pilbara district, where the Hamersley massif extends almost to the coast at Vlaming Head, and again in the vicinity of Roebourne. While little is known of the contours in the vicinity of the Eighty-mile Beach, the Gascoyne, Ashburton, and Fortescue rivers in their lower courses flow over broad alluvial flood-plains.

The surface of the plateau is mostly flat or gently undulating. According to Jutson, the main plateau represents what is probably a vast uplifted peneplain now in a state of arid erosion, bearing the residuals of a former higher plateau which has suffered very considerable erosion. There are no mountains in the sense of large folded and not much denuded systems, and the high points which rise above the existing plateau are in the main either residuals of the former higher plateau erosion, or fault blocks. The highest elevations are found in the Hamersley Range, where Mount Bruce attains 4,024 feet. In the Kimberley district, the King Leopold Range rises to nearly 2,000 feet. This range is the escarpment of the Hann plateau which extends almost everywhere to the coast to the north and west, and is bounded on the east by the Durack Range. It culminates in Mount Hann (2,800 feet). In the south-west, the main physical features are the Stirling Range—a system of isolated peaks, of which Coyaarrup is the highest (3,640 feet)—while to the south is the Porongorup Range, and parallel with the south coast is a system of

isolated hills extending from Mount Manypeak through the Barren Ranges to the Eyre Range and the Russell Range near Israelite Bay. The Darling escarpment averages about 1,000 feet in height, the highest point being Mount William (1,689 feet). This escarpment extends from near the south coast as far north as the Irwin River, and possesses two subsidiary spurs, one extending to the north-west from Gingin, the other, below Bunbury (known as the Roe Range) links the main escarpment with the Dunsborough-Augusta escarpment between Cape Naturaliste and Cape Leeuwin.

Most of the drainage is into the sea. While a number of streams are short and originate near the margin of the plateau, others, like the Fortescue, Ashburton, and Gascoyne, are of considerable length, and originate on the plateau. The rivers of Kimberley rise in the Hann plateau; with the exception of the Fitzroy and Lennard rivers, they are perennial, at least in the plateau area, and they have, together with their tributary streams, eroded narrow valleys or canyons in the soft sandstone. They appear to be young rivers, and several of the smaller tributaries have in places tunnelled through the soft rocks. Most of them rise in the comparatively high rainfall area near Mount Hann.

South of the Fitzroy River, as far as the Avon, the streams are intermittent, and flow only in times of heavy rain. They are, in fact, merely flood channels which carry water in times of flood. They may remain as dry watercourses, containing only a few shallow pools, for several consecutive years, or, on the other hand, they may flow twice or more during the same year. They traverse low flood plains in their lower courses, and a characteristic of the larger streams is the formation of subsidiary channels of "billabongs."

The Swan River marks the commencement of those streams which are more permanent and have eroded broad valleys. They extend southwards to the Denmark and Kalgan rivers. These rivers flow as a rule throughout the winter months, but in the summer are much reduced, sometimes to chains of pools, or in the lower south-west, as for examples the Warren and Frankland rivers, they may be permanent. Some of them, such as the Avon, drain larger watersheds than appear to be indicated on the map as their defined courses, and it is probable that the Avon River once drained a very extensive area, since the chain of salt pans and channels which enters the river at Lake Mcars, can be more or less continuously traced through Lake Brown to Lake Ballard. It is only during exceptional seasons that this system flows to the sea from above Hine's Hill, thus accounting for the salt-pan system of the upper course.

Apart from those streams which find an outlet to the sea, there are a number of watercourses which very rarely carry running water through more than a limited portion of their channels, emptying themselves into extensive flats or clay-pans. Some of these clay-pans are termed "salt lakes." With the evaporation of the water in these depressions substances such as salt and gypsum are deposited. Many of these so-called "lakes" may be of considerable extent, such as Lake Moore and Lake Carnegie. They are either quite isolated, or they are constellated over the interior in a manner that suggests that they once formed old river beds forming part of an ancient river system. The largest of these ancient systems is that which extends from Lake Nabberu to Goddard's Creek near Zanthus. Its ancient course once entered the sea near Twilight Cove, and it constitutes the largest watershed in Western Australia.

The physical features described are important because of their effect upon the flora, and upon the climate. The river systems are important be-

cause not only do they support their characteristic vegetation, but because they have been of importance in plant migrations. The salt pans provide their own halophytic associations.

IV.—GEOLOGY AND SOILS.

Apart from the climatic factor, the edaphic factor is the most important in providing the particular requirements for individual plants, and in determining the characteristics of plant communities. The nature of the soil is dependent upon the original rock formations which are fundamental in determining soil formation and soil characteristics.

The geological fundament of Western Australia is a Precambrian complex, consisting mainly of metamorphic rocks and granite. The granite rocks are exposed in many parts of the territory, particularly in the south, and especially in the Darling and Porongorup Ranges, and parts of the interior of the plateau where they usually occur in the form of convex bosses or tors. Wherever the granite is exposed, or lies close to the surface, it exerts an influence on the plant life, either because of the immaturity of the derived soil, or by reason of the water which it collects. Especially in the arid interior, the flora of the granite rocks stands in marked contrast to that of the surrounding country.

Superposed on these basement rocks are many sedimentary series. Of these, the oldest is that known as the *Nullagine*. The rocks of this series are freely exposed in the Kimberley and Pilbara districts, where they form the most prominent physical features of these areas. In the Kimberley district, on the Hann Plateau, and on the Antrim Plateau, the base of the Cambrian is composed of a series of basalt "flows." The occurrence of basalt in the surface soil determines a distinctive type of savannah or savannah-woodland in which the species of *Themeda*, the "Kangaroo-grass," is dominant, while the indicative prevailing tree is *Eucalyptus Spenceriana*. The "Nullagine" rocks, on the other hand, support on their derived soils a type of steppe or impoverished savannah in which *Triodia* takes a prominent part in the physiognomy.

The Devonian strata, typified by the Oscar and Napier Ranges, are important because of the more richly varied flora which they support. In the Napier Range we find *Melia* common, and several species not found in the neighbouring soil types. The number of endemics here is interesting.

The Permian rocks of the Gascoyne-Ashburton divide appear to be important in more respects than one. The area of their occurrence here coincides with that part of the Mulga-bush formation in which the true Mulga (*Acacia aneura*) is either rare, or entirely absent, and the general physiognomy is more reminiscent of the Pindan country, a type which is common along the lower Fitzroy River, and parts of Dampier Land. The hard-pan soil, so typical of the true Mulga formation, appears to be quite absent from these areas.

The rocks of the Kainozoic Era are associated with characteristic features of the vegetation. They occur as sedimentary formations in many parts of the western and southern littoral tracts, extending as far north as Vlaming Head, and on the south coast as far as Eucla. Between King George's Sound and the Phillips River they occur in the form of siliceous sediments, and support a well-differentiated flora rich in many endemic Myrtaceae and Proteaceae, mostly in the form of heath or low thicket formations; finally, in a calcareous form they provide the basis for the phytogeographically distinct area of low salsolaceous shrub-steppe that characterises the Nullarbor Plain.

The superficial deposit known as laterite by Western Australian geologists, is extensively developed on the Darling Plateau, and occurs in many parts of the southern interior, either capping the higher elevations in the form of a more or less continuous cuirass, or superficial accumulations of pebble-like lateritic nodules with varying amounts of clay and sand. Laterite also occurs near the northern edge of the Hann Plateau between Admiralty Gulf and the Couchman Range in Kimberley, associated there with palm woodlands and a type of sclerophyllous woodland. Laterite also provides the edaphic requirement of the jarrah forest. In the interior it is frequently associated with an impoverished sclerophyllous association in areas of low rainfall, typified by the "Wodjil" type of country, certain *Casuarina* thicket associations, and sometimes with small dwarf woodlands of *Callitris*. The lateritic areas are usually the most deficient in grass, but surprisingly rich in Goodeniaceae.

Finally, mention should be made of the sand which is so characteristic of large areas of the south-west, in the far interior, and in the littoral regions between the Gascoyne and Ashburton rivers, and again between the De Grey and Fitzroy rivers. Within the south-west, on the plateau, it is often difficult to divorce the sand from the laterite as a distinct formation, since laterite so frequently underlies the sand. But in any case, it is on the sand that the shrub-heaths hold undisputed sway, whether the sand be the loose detritus of the coastal plain, the humus sand of the southern littoral, or the more compact yellow or red sand of the interior. Even the sand of the desert supports psammophytes with structural peculiarities, enabling them not only to thrive in a hostile environment, but sufficiently plastic to create new forms. Finally, it is in the sand that the south-west elements have made their furthest advance into the interior.

V. CLIMATE.

The position of Western Australia with reference to its range in latitude (almost equally tropical and extratropical), its low elevation and uniform topography, together with the fact that it lies on the western side of the continent, and is, therefore, subjected to the desiccating effect of the south-easterly trade-winds, are facts of fundamental importance from the climatic standpoint. These facts account for the different climatic systems, and for the great arid middle region which represents the western prolongation of the desert of Central Australia.

Three climatic zones may be recognised: a northern area of summer rainfall of a monsoonal character, with a cool dry season; a south-western area of winter rainfall with a period of summer drought, and a vast central area of low and unreliable rainfall of no marked periodicity, depending entirely upon extensions of the climatic systems which dominate the northern and southern areas.

1. THE CLIMATIC CYCLE.

In order to understand the three climatic areas it is necessary to give a brief account of the operation of the systems.

In January and February, the thermal equator lies over the north, where high temperatures are experienced, especially over the Pilbara and Hamersley districts, which at this time are amongst the hottest regions of the earth's surface. The intense heat causes an inflow of cooler air from the tropical ocean — a monsoonal system which brings rain from the north-west. A "lag" of from four to six weeks which occurs between the atmospheric movements and the apparent solar movement accounts for the retardation of the season which normally extends from December to March. There are two pluvial foci: one where the Hann Plateau extends to the coast between the King Leopold Range and Admiralty Gulf, where the seasonal precipitation exceeds

1,110 mm. (4,300 points), and a secondary focus of much less importance in the Hamersley Range. The absence of meteorological stations on the Hamersley Plateau leaves us in ignorance regarding the local climatic conditions, but the area experiences an increase in rainfall compared with the lower country which surrounds it. From both of these two focal points there is a gradual diminution in the rainfall. The rainfall decreases sharply between Camden Sound and the southern and eastern margins of the Ham Plateau, being about 490 mm. (1,934 points) at Broome, and 567 mm. (2,229 points) at Wyndham, while at Wollal it falls to 249 mm. (978 points). The seasonal isohyets rise to 275 mm. (1,090 points) at Whim Creek and Tambrey, at the northern end of the Hamersley Range, and are doubtless higher within the Range itself. Over the whole of the north the rainfall is very low between the months of April and November, being everywhere less than four inches, and in places below one inch.

A climatic feature of some importance, even if not of any marked seasonal reliability, is the occurrence, usually between the months of January and April, of tropical hurricanes which, born in the Timor Sea, sweep in a south-westerly direction over the sea until they reach the approximate latitude of 18 degrees S., when they curve in a southerly or south-easterly direction and encounter the coast, usually between Broome and Onslow. These violent disturbances may expend their energy soon after reaching the land, or they may continue inland, bringing with them heavy rains, often extending as far south as the latitude of Wiluna, and occasionally to the Nullarbor Plain. They are quite unreliable in their incidence, sometimes occurring twice or more in a given year, at other times they may be entirely wanting for two or more years. Their importance as the principal rain-bringing systems of the great central area, is considerable, since they determine the habitat of the grassland and steppe of the arid region.

While this northern summer monsoonal system is in operation, the southern half of Western Australia lies under the influence of high-pressure systems and summer drought, and except for occasional thunderstorms which are either directly or indirectly influenced by the low-pressure systems of the north, little or no rain falls except in the extreme south-west and southern littoral where the karri forest receives 10 inches of rain, and the entire south coast five inches during this period, due to northward surgings of the systems carried along by the "roaring forties" at all seasons in the Southern Ocean.

As the apparent northern motion of the sun towards the Tropic of Cancer progresses, so the thermal equator shifts to the north away from Australia, and the tropical area lies under a system of high-pressure and drought which continues from April until November or December. This northern "shift" of the atmospheric systems causes a similar northern shift of the so-called "Antarctic" systems, bringing into operation the cycle of winter precipitations. The winter rainfall cycle usually commences in May, either early or late in the month. Sometimes it commences in April, and is then more or less connected with the late cyclonic systems of the north-west (Ashburton-Fortescue) areas. If, as sometimes happens, a powerful southern system should coalesce with a northern active low-pressure system, the result is a general rainfall over the entire west coast, usually regarded as a propitious opening for the southern season. In other years the season develops more gradually from the south, gradually extending northwards, and being without any northern reinforcement remains enfeebled: in such years the inland dry regions usually experience low precipitations. The season retires as it begins, the rainfall systems gradually weakening, until in October the precipitations affect the lower south-west only, and there is a return to drought in November.

The third climatic region, the vast central area, receives nothing of the pluvial wealth of the northern and southern systems. If, as sometimes happens, the southern system sets in over a wide front in conjunction with an active low-pressure northern system, then the central area may receive heavy and useful precipitations, and in such years the Wiluna district may receive more annual rainfall than many coastal stations. On the other hand, the active hurricanes of the mouths of February and March may bring widespread rains to the north-west and extend far inland, bringing disastrous floods. There are thus two months in the year which receive more rainfall than any others—March and June, the former being summer rain, the latter winter rain. Having no rainfall system peculiar to itself, this central region relies entirely upon extensions of the northern and southern systems, experiencing sometimes a comparatively rich rainfall in March, or in June, with lighter precipitations at other times, while on the other hand, one or both of these may fail, and a prolonged period of drought ensues, sometimes extending over two or more years. On the other hand, it may experience two heavy rainfall systems within the one year, as was the case at Wiluna in 1900 and 1942. It is this climatic instability that determines the character of the vegetation of the middle zone. The following table illustrates the annual rainfall for two selected stations: Wiluna being typical for the middle of the dry area, and Katanning in the South-West being typical of the winter rainfall area.

These tables are interesting in that they indicate the high fluctuations in the annual rainfall for Wiluna when compared with the relatively reliable rainfall of Katanning. At Wiluna we have a departure from the mean of + 201 per cent. and — 79 per cent., whereas at Katanning similar figures over the same period are + 45 per cent. and — 26 per cent.

ANNUAL RAINFALL AT WILUNA, 1899–1942, SHOWING ANNUAL VARIATION.
(Annual average rainfall, 1899–1940, 931 points.)

Year.	Annual Total.	Departure from Mean.	Year.	Annual Total.	Departure from Mean.
1899	855	— 8	1922	691	— 26
1900	2,803	+ 201	1923	742	— 20
1901	875	— 18	1924	506	— 46
1902	1,366	+ 47	1925	1,430	+ 54
1903	737	— 21	1926	633	— 29
1904	1,077	+ 16	1927	1,034	+ 11
1905	617	— 34	1928	460	— 50
1906	780	— 16	1929	805	— 13
1907	804	— 24	1930	1,564	+ 68
1908	1,019	+ 9	1931	1,374	+ 49
1909	1,334	+ 43	1932	654	— 29
1910	192	— 79	1933	1,032	+ 11
1911	676	— 27	1934	1,412	+ 52
1912	745	— 20	1935	363	— 62
1913	1,396	+ 50	1936	271	— 71
1914	790	— 15	1937	804	— 14
1915	1,693	+ 82	1938	812	— 12
1916	1,061	+ 14	1939	778	— 16
1917	1,086	+ 17	1940	346	— 62
1918	987	+ 6	1941	1,100	+ 18
1919	935	0	1942	2,770	+ 147
1920	847	— 4			
1921	729	— 22			

RAINFALL FOR KATANNING, 1891-1941.

(Average 1,873 points.)

Year.	Annual Total.	Departure from Mean.	Year.	Annual Total.	Departure from Mean.
		points %			points %
1891	1,236	— 637 34	1917	2,566	+ 693 37
1892	1,568	— 305 16	1918	2,316	+ 443 24
1893	1,621	— 252 13	1919	1,700	— 173 9
1894	1,293	— 580 31	1920	1,975	+ 102 5
1895 ....	....	....	1921	2,080	+ 207 11
1896	1,440	— 443 24	1922	1,605	— 268 14
1897	1,274	— 599 32	1923	2,394	+ 521 28
1898	1,770	— 103 6	1924	1,715	— 168 9
1899	1,784	— 89 5	1925	1,972	+ 99 5
1900	2,133	+ 260 14	1926	2,461	+ 588 31
1901	1,649	— 224 12	1927	1,776	— 97 5
1902	1,429	— 444 24	1928	1,862	— 11 1
1903	2,431	+ 538 30	1929	2,024	+ 151 8
1904	2,023	+ 150 8	1930	1,943	+ 70 4
1905	2,453	+ 580 31	1931	1,915	+ 42 2
1906	1,936	+ 63 3	1932	2,278	+ 405 22
1907	1,948	+ 75 4	1933	1,972	+ 99 5
1908	1,454	— 419 23	1934	2,068	+ 195 10
1909	2,066	+ 193 10	1935	1,700	+ 173 9
1910	2,013	+ 140 7	1936	1,525	— 348 19
1911	1,610	— 263 14	1937	2,215	+ 342 19
1912	1,583	— 290 15	1938	1,384	— 489 26
1913	2,468	+ 595 32	1939	2,718	+ 845 45
1914	1,593	— 280 15	1940	1,072	— 801 43
1915	2,189	+ 316 17	1941	1,857	— 16 1
1916	1,588	— 285 15			Mean var.—16.1

2. TEMPERATURE.

The annual mean temperatures show little correlation with the vegetation in general, but are of importance in limiting the megathermic elements. The mean isotherm of 80° F. for January and February—the driest months in the south—closely approximates to the southern boundary of the Mulga formation, but this may be little more than a coincidence. What is of more importance is the temperature range, especially the diurnal range. While the coastal temperatures remain fairly equable, high diurnal variations are experienced in the interior, especially in the arid areas; even in the south-west they remain extreme at such stations as Bridgetown and Katanning. The variation between the monthly maxima and the monthly minima are proportionately high, being 45° F. at Katanning, 53° at Kellerberrin, and rising to 60° at Mundiwindi. These temperature extremes, especially the diurnal extremes, are comparable in the cases of Wiluna and Mundiwindi, with those of the desert of the Punjab! A study of the monthly isotherms shows an interesting correlation between the temperature and the vegetation, and when applied to the months of maximum precipitation explains satisfactorily the extent of the grassland and woodland formations.

3. HUMIDITY, EVAPORATION, AND WIND.

There are but 36 stations in Western Australia from which data are published concerning temperature and humidity, and these are quite inadequate for the purpose of constructing a map. The appended tables have been compiled for reference and the forming of general conclusions, and contain all the information which has been officially published.

While the 9.0 a.m. readings for relative humidity may be regarded as typical for the 24-hour period in certain coastal areas, it will be at once apparent that this is not so for the inland stations ; the relative humidity tables of monthly mean percentages illustrate this point quite clearly. They exhibit the fact that in the wet forest areas, the range between morning and afternoon (9.0 a.m. and 3.0 p.m.) readings is very slight, while in the sclerophyllous woodland formations it is high, *e.g.*, while at Cape Leeuwin this figure does not exceed 7 per cent., in inland localities it is as high as 24 per cent. Another point that has to be considered is that the 9.0 a.m. readings taken in summer, when in the south the sun rises at 4.30 a.m., are quite a different quantity from those taken in winter, when the sun rises at 7.0 a.m. It is interesting to compare the relative humidity figures for Kellerberrin and Perth with those of Carnamah and Mundiwindi, all of which have different climates. The table of relative humidity for the four consecutive driest months is also instructive, and emphasises still more the climatic extremes of the inland stations.

Information regarding evaporation can be obtained from the figures given for the saturation deficit and the Meyer Ratio. There are only four official evaporimeters in Western Australia, the most inland of which is at Merredin. One at Wiluna or Mundiwindi would be of much value. The following table gives the monthly evaporation in inches for the four stations :—

		Perth.	Narrogin.	Chapman.	Merredin.
January	....	10.370	9.083	11.940	13.151
February	....	8.650	7.570	10.192	10.860
March	....	7.550	6.433	9.226	9.359
April	....	4.670	3.780	6.792	5.979
May	....	4.670	2.361	4.160	3.641
June	....	1.770	1.609	2.629	2.289
July	....	1.730	1.624	2.473	2.098
August	....	2.360	1.864	2.942	2.611
September	....	3.410	2.513	4.055	4.010
October	....	5.340	3.833	6.431	6.527
November	....	7.660	6.156	8.951	9.764
December	....	9.780	8.505	11.391	12.285
<hr/>					
Total	....	65.070	55.331	81.162	82.557

4. RATIO OF PRECIPITATION TO EVAPORATION.

While heat and moisture are the most important of the elements of the climate affecting plant life, water is of importance to the plant in two ways : as soil water, and as atmospheric moisture. The relative humidity depends upon the temperature of the air and the water vapour present ; the hotter the air, the more water vapour it can hold, and the relation of the temperature of the air to its water vapour content controls the loss of water from the aerial parts of the plant. Vegetation is therefore dependent upon precipitation and evaporation.

The evaporating power of the air is expressed by what is termed the *saturation deficit*. This is the amount by which the partial pressure of water vapour in a given volume of air falls short of the pressure at saturation point, and is thus a direct measure of the evaporating power of the atmosphere. In the appended tables, the mean annual saturation deficit values are given, as well as figures for the four consecutive wettest months. They are useful for purposes of comparison, and attention should be paid to the relative values for inland stations.

The Meyer Ratio, which is the ratio of precipitation to the saturation deficit (expressed as an annual ratio), shows a high degree of correlation with $\frac{\text{Precipitation}}{\text{Evaporation}} (P/E)$, and has been employed in several countries as an ecological index, proving of much value in this respect. Mapping the distribution of this ratio with any degree of accuracy is almost impossible, since there are only 36 stations in Western Australia from which data are published. The accompanying map may, however, prove of interest, although the absence of recording stations in the Fortescue district is unfortunate. What the map does show, however, is that the Meyer Ratio determines the approximate boundaries of the forest formations of the south-west, and there is a general correlation between its isopleths and the boundaries of the vegetation provinces. In the north, the 50 isopleth may be taken as representing the southern boundary of the monsoon woodland area.

The $\frac{\text{Seasonal precipitation}}{\text{Seasonal saturation deficit}} \left(\frac{SP}{SSD} \right)$ Ratio is also given for comparison with the Meyer Ratio, with which it shows a certain correlation, but serves to emphasise still further the thermo-pluvial factor. This ratio is the seasonal equivalent of the Meyer Ratio, and as such perhaps serves as a better climatic index in areas which are characterised by a seasonal period of drought.

The $\frac{\text{Seasonal Precipitation}}{\text{Seasonal Temperature}} \left(\frac{SP}{ST} \right)$ Ratio is also important in indicating types of vegetation, but is mainly of value only when considered in conjunction with some other factor.

Finally, amongst the climatic statistics, an important consideration is the variability of the annual rainfall. In the accompanying tables this is expressed as a percentage over the number of years during which records have been taken. It serves as an index for the drought factor, and in this respect is important when considering the climates of the Northern and Southern Provinces in contrast to the Eremaea.

Included in the climatic factor, atmospheric movements are of considerable importance. Especially in the dry interior, the value of wind as a desiccating agent determining the habit and structure of plants is very considerable. Any casual study of the vegetation will at once illustrate this fact. These winds are mainly of two types: the dry prevailing winds that dominate almost the entire interior, and the strong sea winds that mould the structure of certain coastal formations. These latter appear to exert their most powerful effects on the trees of the littoral between Geraldton and Dongarra, and on the dune thickets of the south coast. Their influence is more fully discussed in the chapter dealing with growth-forms.

VI.—RELATIONSHIPS BETWEEN THE CLIMATE AND VEGETATION OF WESTERN AUSTRALIA.

From what has already been stated it will be evident that Western Australia can conveniently be divided into three climatic provinces determined

by the seasonal incidence and amount of the rainfall. The thermic factor is also very important in distinguishing the northern from the southern rainfall areas, while the middle area—the Eremaea—stands as a buffer between the other two.

The main purpose of this thesis has been to define as clearly and as accurately as possible, the three *vegetation provinces* and to correlate them with the *climatic provinces*, for, of all the factors which determine and control the vegetation of the earth, the climatic factor is the most important, and rainfall and temperature are the most important of the climatic elements.

The natural vegetation of a country, especially when unaffected by the biotic, or any other external factor, is the *index of its climatic and edaphic factors*. In Western Australia, where, in the virgin state each association represents an ecological climax, it is possible to learn much concerning both soil and climate from the study of the vegetation. In fact, it is possible to obtain a more or less clear picture of the climatic conditions by such a study. Further, there is a close correlation between the soil formations and the climatic types, and soil surveys in Australia are to a great extent based on the vegetation.

In the Introduction we discussed briefly the elements of the vegetation of Western Australia, showing that in the north, under conditions of summer rainfall and a prolonged season of drought, a type of vegetation existed in which the Palaeotropic Element was at home. In the south-west, an area described as the “triangular-crecentic area extending from Shark Bay to Israelite Bay” came under the influence of the autochthonous element, largely made up of the Antarctic and Australian Elements. It is the region which comes under the active influence of the winter rains, with a summer period of drought. The third area, which we call the Eremean Province, is an intermediate area characterised by a capricious climate, of uncertain regularity, of extreme temperatures, and dependent upon the rainfall systems of the neighbouring provinces for what rain it receives. This area we found to be dominated by the Neo-Australian Element, which is derived from both southern and northern sources of origin.

The boundary of the South-West Province can be determined within comparatively narrow limits, allowing for certain edaphic variations, and is primarily determined by the gradual diminution of the winter rainfall, partly by temperature, and to a great extent by the seasonal variability of the rainfall.

As we pass from the coast towards the interior we notice a change in the formations, from high forest, through woodland and heath to mulga-bush and ultimately steppe and desert. But quite apart from these changes, there is a graduation in the floristic composition. As we approach the boundary of the South-West Province we notice that the autochthonous species become gradually more rare, first we are aware that such plants as *Anigozanthos* and *Conostylis* gradually disappear, and in turn the Epacridaceae cease. Gradually we find an increase in the species of *Eremophila*, of certain Chenopodiaceae, and in the woodland the Zygophyllaceae and Compositae become increasingly important, together with a more open formation of the woodland ground flora. The actual line of the boundary can be determined by the ephedra-like species of *Eremophila*, *Zygophyllum*, and Chenopodiaceae, while in the heath formations we find the last of the south-west elements in *Boronia* and Epacridaceae. These, and some other indicative elements announce that we are passing from the South-West to the Eremaea. Quite apart from changes in the soil, this is brought about by the gradual diminution

in the rainfall, especially the seasonal rainfall. The following table illustrates this diminution :—

Station.		Altitude. ft.	Distance E. or W. of escarpment.	Rainfall (points).
Fremantle	....	....	6	20 miles W.
Perth	....	197	10	W. 3,467
Guildford	....	30	5	W. 3,393
Mundaring	....	975	6	E. 4,352
Chidlow	....	983	10	E. 3,796
Northam	....	494	40	E. 1,711
Meckering	....	640	60	E. 1,526
Cunderdin	....	733	75	E. 1,458
Tammin	....	800	85	E. 1,378
Kellerberrin	....	815	100	E. 1,329
Doodlakine	....	840	110	E. 1,235
Merredin	....	1,042	135	E. 1,292
Walgoolan	....	1,055	155	E. 1,196
Southern Cross	....	1,157	200	E. 1,052
Coolgardie	....	1,394	315	E. 1,009
Kalgoorlie	....	1,234	337	E. 951
Rawlinna	....	603	570	E. 637
Loongana	....	603	680	E. 615

A corresponding diminution occurs everywhere ; to the east of Geraldton, for example, and to the north of Esperance, the diminution takes place to a greater degree over a given area, and the example quoted above is the longest transect possible with so many stations. It is this gradual diminution that accounts everywhere for the gradual changes in the vegetation, modified only by the edaphic factor.

In constructing a climatic map of Western Australia which would conform to the main types of vegetation, it was obvious that any consideration of the annual isohyets alone would be insufficient. For amongst other considerations, such rainfall statistics do not take into account the useful seasonal rainfall, and give no indication of seasonal periodicity, nor do they indicate those areas which experience a pronounced drought factor in the annual climatic cycle. In other words the essential elements of temperature and rainfall periodicity are not indicated, although in a very general way there is some correlation between the annual rainfall figures and the principal types of vegetation. What is required therefore is a map embodying both pluvial and thermal factors, but this is impossible, because the temperature figures were obtainable from 36 stations only.

A means of employing the temperature factor was reached by considering the seasonal incidence of the wettest period of the year. At first the six wettest months were employed, but were later abandoned in favour of a season employing the four wettest consecutive months, and the four consecutive driest months. The isohyets obtained by a consideration of the four wet months, referred to throughout the tables as the "season," were found to coincide very closely with the boundaries of the three provinces of the vegetation. The line of 175 mm. winter (May-August) rainfall is, in fact, exactly a very distinct line of separation, clearly defining the limits of the autochthonous elements of the south-west, and also determining the western limits of those elements proper to the Eremaea. It is the Western Australian equivalent of the "Goyder Line" of South Australia. Apart from its significance in the vegetation of Western Australia, it may well prove to be a line of considerable importance in future agricultural development.

The same value in the seasonal isohyets of the northern wet season (the four consecutive months which lie between December and April, i.e., December-March, or January-April), 175 mm., was found to correspond very closely with what is considered to be the boundary of the northern savannah types, and also to conform to the limits of many Indo-Malayan groups in northern Australia.

The third climatic province is that in which the rainfall for the four consecutive wettest months is less than 175 mm. It will be noticed here that these four months are not uniform over the area, but that the winter system (May-August) extends along the southern and western margin of the Province, as the December-March or January-April season does in the north. The middle zone however, experiences its four wettest months between March and June, exactly those months which experience the northern and southern maximum extensions of precipitation. The intervening months, April and May, have a lower rainfall than either March (summer or northern) or June (southern or winter) rainfall. This seasonal incidence has, of course, a powerful thermic factor which is reflected in the relative importance or absence of grass in the formations. Whereas the Northern Province is essentially the area in which the Indo-Malayan Element is important, and grass the predominant ground flora, and the South-West Province the area deficient in grass, but in which the autochthonous flora holds undisputed sway, the characteristics of the intermediate Eremean Province correspond to an area in which the flora shows affinities to the regions both to the north and south, admitting both to a certain extent, but having at the same time its own distinctive impress, forcibly expressing the capriciousness of its climatic factor and preserving a strange duality in its herbaceous species—a tendency towards grass under warm influences, and dicotyledonous herbage under cooler conditions of moisture.

The three climatic Provinces thus delineated are:—

The Northern Province, the South-West Province, and the Eremean Province.

VII. THE PROVINCES AND THEIR FORMATIONS.

1. THE NORTHERN PROVINCE.

The Northern Province is characterised by the role which is played by the Indo-Melanesian Element, by its formations, in which grass takes a prominent part as the most important ground flora, and finally by the predominance of megathermic plants. Except in the riverain and mangrove formations, grass occurs almost everywhere. Sclerophyllous shrubs are in the main either entirely absent or very scarce, and the trees are usually sparsely distributed. In the southern dry areas *Triodia* steppe and Pindan occur, with savannah on the alluvial soils. Only where laterite is present do we find any attempt at a sclerophyllous formation, and these formations bear a distinctive physiognomy by reason of the frequent occurrence of palms and broad-leaved shrubs. Even here the coarse grasses assume an importance which causes a sharp contrast with similar formations in temperate latitudes.

It is interesting to consider briefly the role taken by the Indo-Melanesian plants in this Province. Apart from the mangrove formations which fringe the coast and become of sufficient size and density to constitute a forest in the estuaries, the real home of this Element is to be found in the riverain forests where, under the influence of telluric water, species which are more properly those of the rain forest find a suitable environment independent of atmospheric precipitations. This is especially true of the black muddy soils, or soils rich in humus. Where the river flats are well drained, the formation ceases to exist.

The occurrence of epiphytic orchids, tall climbing ferns, dense forests of ead-juput (*Melaleuca leucadendron*) and many broad leaved trees such as *Sarcocephalus*, *Ficus*, *Randia*, *Sesbania grandiflora*, *Barringtonia*, and *Carallia*, with occasional species of broad leaved *Terminalia*, renders the formation at once distinctive, especially when the density of the canopy is considered and the predominance of species of *Pandanus* and ground flora of ferns.

The monsoon woodland occurs in the higher rainfall regions, but is most highly developed in the sandstone areas. Apart from the *Eucalyptus* species which form the greater part of the arborescent growth, there is a distinctive Indo-Malayan impress by reason of the number and density of Indo-Malayan arborescent plants, such as *Terminalia*, a number of Apocynaceae and Rubiaceae, e.g., *Timonius*; species of *Diospyros*, *Maba humilis*, *Planchonella*, and *Lucuma*, and many smaller shrubs, with *Cycas* and groves of *Livistona*. Important amongst the species of *Eucalyptus* are *E. miniata*, *E. tetrodonta*, *E. terminalis*, and *E. brachyandra*. Deciduous species of *Sterculia* and *Brachychiton* are also common. In fact, the deciduous character of the foliage of many species, including *Eucalyptus brachyandra*, gives to the formation an appearance which is unique amongst the formations in Western Australia.

The savannah woodland of Kimberley, which extends generally southwards to the Fitzroy River, has much in common with the monsoon woodland, but is much more open in composition, with a greater abundance of perennial grass, and *Eucalyptus* plays a more important role. There are two principal types:—the basaltic savannah, and the sandstone savannah. The former consists of almost pure stands of *Eucalyptus Spenceriana*, associated with *Eucalyptus clavigera*, and the less important scattered trees of *Eucalyptus latifolia* and a few minor species. *Gossampinus heptaphylla*, *Erythrina vesperilio*, and species of *Terminalia* are amongst the most important deciduous species, together with *Sterculia*. There are very few shrubs, with the exception of *Cochlospermum* and *Maba*, and the ground is densely covered with perennial grasses, notably *Themeda triandra*. The trees are well spaced, and apart from the species of *Eucalyptus*, the only prevalent evergreen trees are *Erythrophloeum*, *Hakea*, and *Grevillea*. The Indo-Malayan Element is not well represented, except in the herbaceous species, and floristically it is the poorest of all the tropical formations.

The sandstone savannah, on the other hand, is much richer floristically. It does not possess the uniform character of the basaltic savannah, and there is a more marked intrusion of the Indo-Malayan Element. *Eucalyptus terminalia*, *E. tetrodonta*, and *E. miniata* are amongst the commonest of the *Eucalyptus* trees, with isolated groups of *Eucalyptus alba* on the low-lying flats. The Proteaceae are represented by *Persoonia falcata*, several species of *Grevillea* and *Hakea*, with *Grevillea chrysodendron* and *Banksia dentata* in the swampy depressions. But it is above all the strictly tropical groups that give to the sandstone savannah its distinctive character; *Celastrus*, *Denhamia*, *Ficus*, *Terminalia*, *Eugenia*, *Careya*, *Celtis*, *Maba*, and many other woody plants, including the common *Carissa lanceolata* being met with almost everywhere, together with the deciduous Sterculiae and the grotesque Baobab tree (*Adansonia Gregorii*). The herbaceous and sub-shrubby plants are represented here to a degree not found elsewhere in the tropics, the brilliant flowers of *Hibiscus*, *Cienfugosia*, and *Thespesia* being amongst the most conspicuous of the Malvaceae and Tiliaceae, which are predominant. The herbaceous flora, too, is rich in widely diversified species and growth forms. While the commonest plants are the grasses which occur in splendid profusion, the Asiatic, Australian, and African groups being mixed together, but usually predominated

by species of *Sorghum*, one of which (*S. intrans*) attains a height of six or eight feet. There are also a multitude of dicotyledonous herbs, including *Ptilotus* and *Trichinium*, *Spermacoce*, many species of the Scrophulariaceae, Leguminosae, and plants belong to the Centrospermae.

The swampy areas are mainly covered by Cyperaceae belonging to many genera, with *Mitrasacme*, *Byblis*, and *Utricularia*, where the soil is perennially moist.

Whereas the basaltic savannah woodland maintains its distinctive physiognomy throughout, the sandstone savannah woodland, on account of the deeply eroded nature of the country, is remarkably diversified. No large uniform areas are to be seen. Either the plateau is flat, or it is seamed with wild deep canyons, and wide eroded flats. The swampy land referred to occurs usually in depressions in the plateau itself, or in the broad valleys flanked by steep cliffs. The canyons and gorges carry a profusion of lithophilous shrubs or trees, such as *Ficus*, *Erioglossum*, *Dodonaea*, *Boronia*, *Calythrix*, and the giant *Verticordia*, *Ervatamia*, *Solanum*, and a number of species in which the temperate Australian groups are mixed with the tropical. The high plateau, on the other hand, supports plants which are more typical of the dry steppe zone—*Triodia*, *Grevillea*, *Callitris*, *Dampiera*, *Cassia*, *Eucalyptus papuana*, and *E. setosa*, and *Acacia* species of the Phyllodineae, notably *A. tumida*, *A. Luehmanni*, and *A. sericata*.

This contrast is remarkable, and exhibits the fact that the Indo-Malayan Element in the flora finds its highest expression in the low-lying moist soils, while the more arid situations are almost entirely populated by xerophytic Australian species which are alone able to thrive in this unfavourable environment, for it must be remembered that although the Hann Plateau of Kimberley receives a rich rainfall in its wet season, the six cool months experience a drought period scarcely equalled, even in the Eremaea, and that the mesophytic and hydrophytic elements of the flora, including these Indo-Malayan species that are not deciduous, are restricted to soils in which telluric water supplies their moisture requirements.

The King Leopold Range marks the southern boundary of the savannah woodland, and we enter into a region of lower rainfall. The principal formation is savannah carrying isolated or scattered trees, mostly *Eucalyptus* and *Acacia*, and a dense ground-covering of grass and herbs. Where the soil is rich in quality, or subjected to periodic inundation we find a richer flora, in which a number of tropical African grasses grow in abundance mixed with genera which are either gerontogeous, or with a few strictly Australian types, together with several Indo-Malayan or paleotropic herbaceous species, especially legumes. Here we also find bipinnate Acacias, especially *A. Farnesiana* and *A. Bidwilli*, and the outposts of the Indo-Malayan arboreal Element—plants such as *Bauhinia*, *Pithecolobium*, *Dichrostachys*, and a few others of less importance. The savannah is only well represented on the plains, especially in alluvial soils. Where the soils become more sandy, or of a gravelly nature, the physiognomy changes, and we enter into the Pindan country near the Fitzroy River. The Pindan country is perhaps the tropical equivalent of the Mulga bush of the Eremaea, but its woody plants, mostly *Acacia*, are more densely crowded, and the *Eucalyptus* trees become more depauperate. *E. setosa* and other *Corymbosae* are the dominant species. Associated with the shrubs and dwarf trees are tall coarse grasses and succulent herbage, such as *Portulaca*, *Trianthema*, and *Sesuvium*. In its more impoverished form it leads to the steppe and ultimately to the desert some distance to the south of the Fitzroy River.

The main area of the Northern Province is connected with the Fortescue-De Grey region by a narrow neck of Pindan country in the vicinity of Wollal. The Fortescue-De Grey region, which centres round the Hamersley Range has been referred to previously as an area which is almost an "island" in the Eremaea. The whole of this area is not well known phytogeographically, but the extensive development of savannah, the climatic conditions, and the existence of many vestiges of the Indo-Malayan Element, render its inclusion within the Province necessary. There are, however, several important changes. The deciduous species no longer exist, with the single exception of *Brachychiton australis*, but the prevalence of such plants as *Owenia*, *Livistona*, *Atalaya*, *Bauhinia*, *Dichrostachys*, and a number of others, including certain lithophytes and mesophytic herbs, shows that this country has many resemblances to that of the north. In the savannah, *Sorghum*, *Eulalia*, *Chrysopogon*, *Heteropogon*, *Iseilema*, and *Astrebla* remain as important constituents—plants which are almost totally absent from the Eremaea. Here again the savannah is restricted to the alluvial soils, merging into a type of Pindan and the Triodia steppe. Along the rivers and in the declivities of the Hamersley Range we find such plants as *Astrotricha*, *Ficus*, *Terminalia*, and *Clerodendron*, whilst the Rubiaceae and Scrophulariaceae, together with several megathermic Compositae, remain in sufficient numbers to be regarded as important. The actual western boundary of the Northern Province near the Ashburton River is not known, but occurs near Mardie in the west, and includes Red Hill, while to the east it extends to Marble Bar and Nullagine. Whether or not the Province extends to the south of the Hamersley Range is not known with certainty.

2. THE SOUTH-WEST PROVINCE.

The South-West Province is distinguished floristically by the rich development of the Australian and Antarctic Elements. This development is most powerfully expressed towards the cusps of its triangular-crescentic area of distribution, both in the north, between the Hill River and the Murchison River, and in the south-east between the Phillips River and Israelite Bay. There is, indeed, a close connection between the plants of these two widely separated areas, as for example the restricted distribution of *Phymatocarpus*, *Conothamnus*, and certain species of *Eucalyptus* and *Adenanthera*, as well as certain close affinities in a few groups such as *Conostylis* and *Anigozanthos*. Both areas represent the richest areas in species and forms in the entire province. It is also noteworthy that these two areas are precisely the regions where the climatic and epharmonic gradients are the sharpest, and thus competition between Eremean and southern forms least possible of extension.

Other characteristics of the South-West Province are the predominance of sclerophyllous shrubs in every formation, either as undergrowth in the forest and woodland, or crowding the heaths. The floristic wealth of these heaths is probably unparalleled anywhere else on the earth. Important, too, is the paucity of herbaceous plants, particularly the grasses, although the Cyperaceae, Restionaceae, Haemodoraceae, Liliaceae, and Compositae make up to some extent for this deficiency. When one considers the facility with which certain exotic grasses establish themselves, as for example in the tuart country, this paucity of the indigenous grasses is difficult to understand. It may be the story of the warfare which is supposed to exist between woodland and grassland, and that the climatic conditions favour the development of trees and shrubs, or it may be a question of the biotic factor, or of species migration, for the greater number of the indigenous grasses, with the exception of a few such as *Festuca*, *Danthonia*, *Stipa*, and *Amphipogon*, appear to be of palaeotropic derivation, and have not been able to obtain a foot-

hold in the South-West because of their inability to surmount the climatic barriers. In any case, the number of genera of grasses in the South-West Province is exceedingly small, and the area possesses but one endemic genus, the monotypic *Diplopogon*.

Lastly, it is the high degree of endemism within the Province that is one of its outstanding characteristics. This has already been remarked upon, and the figure is about 80 per cent. Unlike the Northern and Eremean Provinces it has borrowed little or nothing except from the ancient ancestors from which it has evolved, and of course excepting those maritime or littoral plants which have suffered oceanic transportation, and which have obtained a foothold in an environment which is not typical of the general area.

Apart from the littoral halophytic and dune formations which require no particular attention beyond the fact they they contain more or less cosmopolitan maritime, or Eremean elements, the south-western formations are mainly woodland and heath types. In the extreme south-west, in the area bounded by the 500 mm. seasonal isohyet, the forest formations predominate except where sandy coastal plain or swamps provide unsuitable edaphic conditions. To the east of this area, between the seasonal isohyets of 500 mm. and 200 mm., the savannah woodland and heath formations predominate, while below the 200 mm. isohyet, sclerophyllous woodland and sand heath dominate the landscape. While the above isohyets may be said to determine broadly the limits of these formations, the edaphic factor is important in determining the formations under drier conditions. For example, while the edaphic factor is not so active in the forest areas, it does to a considerable extent determine the sclerophyllous woodland, savannah woodland, and heath formations, the sclerophyllous woodland always being determined by the soil, thus dovetailing into the climatic confines.

Formations which are more strictly edaphic are those of the swamp, the laterite, and the granite. It would, however, be quite beyond the scope of this essay to deal with these at any length, and the merest outlines must suffice.

(a) THE FOREST FORMATIONS.

(i) *The Jarrah Forest.*

The distribution of *Eucalyptus marginata* is bounded by the 400 mm. seasonal isohyet, but it is only on the lateritic soils that the forest formation exists, for although it occurs freely on the sandy soil of the coastal plain, it does not in this environment constitute a forest. The jarrah forest is a true sclerophyllous formation, remarkable for the paucity of other tree species, for it is not a social species, and its only associates are *Eucalyptus patens* and *E. calophylla*. At the same time, this is surely one of the outstanding characteristics of the *Eucalyptus* associations. These trees are rather widely branched, but suffer little or no overlapping of their crowns, the result being a forest canopy easily penetrated by light. Amongst the *Eucalyptus* trees are smaller trees, mostly Myrtaceae, Proteaceae, and Casuarinaceae, e.g., *Persoonia*, *Banksia*, *Xylomelum*, *Casuarina*, and *Agonis*, the only one of which that exhibits any marked degree of plagiotropism being *Banksia grandis*, and to a lesser extent *Xylomelum occidentale*. The undergrowth is composed of sclerophyllous shrubs from less than a metre to two or three metres high, predominantly Myrtaceae, Proteaceae, and Leguminosae. In certain areas *Macrozamia* becomes important, together with *Xanthorrhoea*, while towards the south the remarkable suffrutescent *Podocarpus Drouyniana* assumes importance.

Floristically, however, the formation is not richly endowed. The herbaceous plants are poorly represented, and there are but a few lianes, mostly *Hardenbergia*, *Kennedyia*, and *Clematis*. It has been stated previously that the lateritic formations are usually poor in species, and this rule holds good for the jarrah forest. The forest attains its best development in the vicinity of the Blackwood River, where the undergrowth, due to a heavier canopy, becomes less dense, and *Pteridium* becomes important in the lighter soils. The jarrah and its competitive trees are rough barked, a characteristic which is unusual amongst the trees of southern Western Australia.

(ii) *The Karri Forest.*

The karri forest stands in sharp contrast to the jarrah forest by reason of its larger trees, the mesophytic undergrowth, and the better development of an under-storey of trees, in which *Casuarina decussata*, *Agonis flexuosa*, *Banksia*, and *Hakea* take a prominent place. The shrubby undergrowth is higher, *Acacia pentadenia* one of the Bipinnatae, with large-leaved shrubs such as *Trymalium*, *Chorliaena*, *Hovea elliptica*, and *Albizzia*, and in the open spaces, areas of tall *Pteridium*, often exceeding two or three metres in height. The sclerophyllous plants of the jarrah forest have larger, less sclerophyllous leaves, and the smaller shrubs and herbs are of straggling widely-branched habit. Indeed, the wide branching and interlocking of branches is at once in marked contrast to the shrubs of other formations, as well as the tendency for species to become ombrophytes. The principal shade is, however, not due to the density of the canopy provided by the principal trees, for although these, the karri (*Eucalyptus diversicolor*), tingle trees (*E. Jacksoni* and *E. Guilfoylei*), and Marri (*Eucalyptus calophylla*) are precisely those that have the widest and most horizontal branching habit of all the south-western species of the genus, they do not give much shade. The shade is provided by the under-storey of smaller trees, especially *Casuarina decussata* and *Banksia grandis*, or the other species of *Banksia*. The true ombrophytes are those species which live on the forest floor, such as *Dampiera hederacea*, the species of *Boronia*, *Tremandra*, and *Opercularia*.

Unlike the jarrah forest, the karri forest secures its edaphic requirement in the soils derived from the granitoid or gneissic rocks which more or less determine its occurrence in its general area of distribution, and account for outlying areas on the Porongorup Range, and near Mount Manypeak. The karri forest occurs between Denmark and the Blackwood River estuary, where the rainfall during the six driest months exceeds 200 mm. The density of the vegetation, both amongst the arborescent or fruticose species, together with the occasional occurrences of epiphytic ferns, gives to the karri forest a physiognomy not possessed by any other plant formation in Western Australia except the riverain forest of the Kimberley Division. It is really a type of temperate rain forest.

(iii) *The Tuart Forest.*

The tuart forest is a type of savannah forest in which the trees of the tuart (*Eucalyptus gomphocephala*) attaining a height of 40 metres, dominate the forest in almost pure stands, being only rarely associated with such species as *E. calophylla* and *E. cornuta*. It is edaphically confined to the littoral limestone of the western coastal plain, the range of the species extending from near the Hill River to the Sabina River near Busselton. It is only in the southern part of its range, where the summer (November-April) rainfall exceeds 125 mm. that it attains to the proportions of a forest in its species. Here it is a true savannah formation, with an understorey of

Agonis and *Banksia*, *Melaleuca* and *Hakea*, with a herbaceous ground covering in which the shrubs are comparatively few. To the north the undergrowth becomes shrubby, but retains something of the nature of savannah, and when the shrubby undergrowth is destroyed there is a tendency towards the development of grass at the expense of the shrubby growth, thereby indicating a succession in the direction of pure savannah forest. In contrast to the jarrah, karri, and marri, the tuart tree is of the "box" type, the real environment of which is the savannah formation. ("Box" is a vernacular term applied to *Eucalyptus* trees with entirely rough grey bark.)

(b) THE WOODLAND FORMATIONS.

(i) *Savannah (temperate) Woodland.*

In the granitic soils of the jarrah forest of the Darling Range the wandoo tree (*Eucalyptus redunca* var. *elata*) occurs where the subsoil is of a clayey nature. Here it never dominates the forest, but is found in small numbers in the granitic areas. To the east of the 385 mm. seasonal isohyet however, it becomes the dominant tree, usually associated with *Eucalyptus foecunda* var. *loxophleba* and *Acacia acuminata*, forming open savannah-like country with a low shrubby or herbaceous undergrowth. It is usually associated with shallow granitic soils, but extends into deeper clay soils, especially in the south, or into sandy country to the east and north, ultimately (about the 200 mm. seasonal isohyet) becoming associated with decomposed laterite. Towards the northern part of its range the species is increasingly associated with *E. foecunda* var. *loxophleba*, and *Acacia acuminata*, giving place to these two latter species entirely in the latitude of Arrino, to the north of which the savannah woodland formation is composed almost entirely of these two species as far north as Northampton. To the south, in the vicinity of Wagin, the character of the savannah woodland undergoes a change, and *Eucalyptus occidentalis* becomes important, especially in the low-lying clay soil, while the wandoo becomes restricted to the sand, until finally, in the vicinity of Cranbrook, the wandoo disappears entirely, and its place as a savannah tree is taken by both *Eucalyptus occidentalis* and *E. cornuta*, the former in the clay soils, and the latter confined to granitic areas. Between Cranbrook and Gnowangerup the zone limited by the 385 and 200 mm. isohyets curves sharply eastwards, to extend along the south coast, and here the two trees continue as far east as the Russell Range, forming in places areas of open grassy granitic country in which either or both trees occur. This is country more suitable for grassland development than the area to the north, on account of the higher summer precipitations. The formation ceases to exist to the east of Israelite Bay. Throughout the whole extent of its area of distribution it is intersected by zones of sand-heath.

(ii) *The Sclerophyllous Woodland.*

Somewhere in the vicinity of the 225 mm. isohyet the loamy soils support a type of woodland which is in contrast to the savannah woodland because of the density of its arborescent species, the greater development of shrubs, and the paucity of grasses except those of a harsh tussocky nature. The formation usually occurs on low-lying soils, and the woodland either consists entirely of trees about 25 metres with an undergrowth of shrubs about a metre high, and bare soil beneath, or there may be a development of shrubby *Eucalyptus* species known as mallees. The formation extends as far east as Zanthus, and northwards to the mulga bush formation, but its eastward extension is sharply limited by the limestone soil of the Nullarbor Plain.

In the western area of its distribution, between the 200 and 150 mm. isohyets the arborescent species are few, comprising three principal species—*Eucalyptus salmonophloia*, *E. longicornis*, and *E. salubris*, but to the east there is a greater admixture of the species, at least a dozen trees entering into the composition. Within the South-West Province, *i.e.*, as far as Merredin, there is a comparatively rich development of shrubs, amongst which *Acacia* and *Proteaceae* are predominant, but to the east of the provincial boundary there is a notable development of *Myoporaceae* and *Chenopodiaceae*, the former being shrubs 3–5 metres high, mostly with an ephedra-like habit, while the *Acacia* become fewer, and the woodland undergrowth more sparse and more and more given over to *Chenopodiaceous* species. Where the soil becomes more alkaline, the *Chenopodiaceae* become increasingly important, often associated with *Amarantaceae* and shrubby *Compositae*. This is particularly the case to the east and south of Widgiemooltha, where the grey-bush (*Cratystylis conocephala*) assumes great physiognomic importance, and *Melaleuca* becomes more common, while the tree species become more social than in any other formations, but all have more or less the same characteristics, so that field recognition becomes difficult. For example, at Norseman there are at least fifteen *Eucalyptus* species in close association.

The sclerophyllous woodland formations are everywhere limited by the edaphic factor—nowhere do they occur on sand—and typically they inhabit the alluvial depressions, the broad red-soil plains, or finally the alkaline soils of the “lake” country. The last-mentioned type is to be found principally in the Lake Brown-Yilgarn country, southwards to Kondinin and Lake King, while to the east, there is a broad area of the formation between Widgiemooltha and Dowak, extending some distance westwards, and eastwards almost to Balladonia. The soil is more or less saline, and the *Eucalyptus* species are in the main different from those of the red clay soils. *Eucalyptus Brockwayi* and *E. leptophylla* take the place of *E. salmonophloia*; *Eucalyptus campaspe* the place of *E. salubris*, and *E. Flocktoniae* and *E. oleosa* var *transcontinentalis* the place of *E. longicornis*. Besides the low undergrowth of *Chenopodiaceae*, there are larger shrubs, such as *Melaleuca pauperiflora* and *M. quadrijaria*, known as “Boree”, and extensive tracts of *Cratystylis conocephala*, as well as several broom-like species of *Eremophila*. Where the red clay soil woodland occurs there is a notable reduction in *Chenopodiaceous* plants, and the undergrowth is lower and of a more uniform stature. *Acacia* and *Myrtaceous* species predominate.

A curious fact which is worth mentioning here is that with the increase of summer rains to the south of the Coolgardie district, and in the Eyre district, the grasses become of increasing importance. For example, already at Dundas, grasses are important in the undergrowth of the open woodland, and between Mount Holland and Dowak it is not uncommon to find, after burning, especially with summer rains, areas of woodland country carrying a fairly dense covering of grass. This state of things represents a succession in the woodland which appears to be only temporary, for ultimately the *Eucalyptus* seedlings grow into trees and shrubs, and the country reverts to woodland. At the same time, areas occur which appear to be permanently clothed with grass; these small areas represent natural fields in the woodland, and appear to be a permanent feature of the southern sclerophyllous woodland zone. The best known example is perhaps Grasspatch, an area of a few hundred acres, which in its virgin condition consisted entirely of grasses, closely surrounded by the woodland. Other examples of these grassy “oases” occur between Norseman and Balladonia, but are mostly little more than a few acres in extent. They

are, however, important since they indicate that under conditions of repeated firing or clearing, there is a distinct tendency towards a grassland succession.

(c) LATERITIC FORMATIONS.

Apart from the jarrah forest, the lateritic formations in south-western Australia do not support arborescent species with the exception of two types. The first is the wandoo formation, which in the eastern area of its range on the fringe of the savannah formation occurs on lateritic rises as a small tree forming open woodland with a characteristic undergrowth in which certain species of *Acacia*, *Callitris Morrisoni*, and *Casuarina campestris* are characteristic plants. This passes almost imperceptibly into a type known as "Wodjil country," in which *Acacia* becomes predominant (especially *Acacia Beauverdiana*, *A. signata*, *A. neurophylla*, and other species of similar habit—all rigid erectly-branched markedly sclerophyllous shrubs). *Casuarina campestris* is also a characteristic species, either forming low dense thickets, or in more open formation associated with *Acacia*, *Hakea multilineata*, *Dodonaea*, and certain Proteaceae. This formation remains poor in herbaceous species. It extends from the eastern margins of the South-West Province into the Eremean Province, even to the boundary of the mulga bush.

In the western part of the savannah zone, bordering on the jarrah forest there are two important types, more or less restricted to hills and rising ground—the isolated woodlands of *Eucalyptus accedens*, and the Mallet country. The former enters to a certain extent into the composition of the marginal jarrah country where the subsoil is clay, and sometimes is found in association with wandoo itself. It attains to its highest development between Toodyay and Williams to the west of the Great Southern Railway, and again between Bindoon and Mogumber. The type is characterised by its stony soil, and the density of the sclerophyllous undergrowth in contrast to the pure wandoo formation.

Mallet is the name given to two or three species of *Eucalyptus*, especially the brown mallet (*Eucalyptus astringens*) and the blue mallet (*E. Gardneri*). These trees, which grow in dense formation, occupy the lateritic hills of the wandoo zone between Pingelly and Ravensthorpe, attaining their highest development between Pingelly and Wagin to the east and west of the Great Southern Railway. Both species readily germinate after the country is denuded by fire, forming dense thicket-like areas over the lateritic hills, with a shrubby undergrowth in which *Oxylobium parviflorum* and *Dryandra* are common, together with certain endemic species. To the south of Wagin, the mallet areas occur on lower-lying ground, but not in depressions, while the two species extend in a mallee form almost to Esperance.

(d) FORMATIONS OF THE GRANITE ROCKS.

Throughout the interior, the basic granite is exposed in small rounded hills or tors, often quite devoid of soil. These masses serve to collect amounts of rain water which runs off their sides, or collects in shallow pools on the rock. The areas thus receive more soil moisture around their bases than the surrounding country, and this is of importance to the vegetation. There are a number of plants entirely confined to the granite rocks and their vicinity. Amongst the trees, the most characteristic is perhaps *Casuarina Huegeliana*, which attains a height of five or six metres, with heavy pendulous branches. Other characteristic species in the interior are *Leptospermum erubescens*, *Kunzea sericea*, a shrub with handsome scarlet flowers produced in great abundance, and often growing out of crevices in the bare rock, and the two

ferns *Pleurosorus rutifolius* and *Cheilanthes tenuifolia*. *Plagianthus Helmsii* is perhaps more characteristic of the Eremaea, but characteristic of the granite rock anywhere through the South-West Province and most of the southern Eremaea are the pin-grass (*Borya nitida*) and certain species of *Drosera* and *Orchidaceae*. Certain south-western elements are, through the additional moisture of the granite soils enabled to obtain a foothold far beyond their usual climatic range, and thus we find *Nuytsia floribunda* growing as far inland as Yorkrakine, while *Hakea prostrata* and *Hypocalymma angustifolia* may be seen as far inland as Southern Cross. It is during the winter, however, when the shallow moist soil underlaid by the impervious granite rock receives its abundance of moisture that the granite rock flora is richest in species ; then the ground is carpeted with a wealth of bulbous Liliaceae, *Orchidaceae*, *Drosera*, *Stylium*, and *Polypompholyx*, together with certain ephemeral Compositae and Centrolepidaceae. There are, in addition, a number of species quite restricted to the granitic formations, such as species of *Ricinocarpus*, of *Acacia* (e.g., *A. restiacea*, *A. lasiocalyx*), *Eucalyptus*, *Melaleuca*, and other *Myrtaceae*, as well as species of *Hydrocotyle*, *Anthoercis*, *Lobelia*, and many others.

(e) SWAMP FORMATIONS.

Extensive alluvial formations occur at intervals on the coastal plain between the Hill River and Israelite Bay. In their most typical form they occur on sandy country between the edge of the plateau and the coast, and retain their surface moisture throughout the winter and frequently until the end of the year or, on the other hand, they are perpetually moist, especially in the southern areas of their distribution. While it is quite impossible here to go into details, it may be said in general that these areas are rich in annual herbs in contrast to the surrounding country, and that *Myrtaceae* and certain *Proteaceae* make up most of the shrubby and arborescent species. The number of endemics is not high when compared with other formations such as the heath. Prominent amongst the trees are the species of *Banksia*, especially *B. littoralis*, *B. occidentalis*, and *B. sphaerocarpa*. The *Myrtaceous* genera include several species of *Melaleuca*, especially *M. parviflora* and *M. raphiophylla*, a number of species of *Agonis*, one of which (*A. juniperina*) attains to a height of 15 metres ; *Leptospermum*, *Beaufortia*, *Astartea*, *Viminaria*, *Boronia*, *Dasypogon*, *Baxteria*, *Cephalotus*, *Oxylobium*, *Conospermum*, and generally the greater number of the Restionaceae and Cyperaceae. The herbaceous plants comprise a number of annuals and bulbous or tuberous-rooted plants such as *Tribonanthes*, certain *Orchidaceae*, *Polypompholyx* and *Utricularia*, *Stylium*, *Levenhookia*, *Triglochin*, *Drosera*, *Villarsia*, certain Compositae, especially the *Angianthinae*, *Epacridaceae*, and *Proteaceae* (especially *Franklandia*, *Conospermum*, and *Adenanthera*), and certain *Goodeniaceae*, especially *Diaspasis* and *Anthotium*.

Mention was previously made to the distribution of the phyllodineous *Acacias*, and the fact that two species inhabited the swampy areas. It is also noteworthy that certain genera which are well developed in the dry areas, even in the far away Eremaea, are represented in the alluvial and swamp formations. I would specially mention *Bossiaea*, *Lachnostachys*, *Anthotium*, *Dampiera*, *Hakea*, and *Melaleuca*. *Bossiaea* and *Lachnostachys* are as well represented in the dry interior as in the swamps, or even more so, while *Dampiera* and *Anthotium*, both of which are typical of most swampy areas, are well represented in the dry lateritic soils of the Eremaea.

(f) HALOPHYTIC AND DUNE FORMATIONS.

The halophytic formations will be dealt with at greater length under the chapter on the Eremean Province, since these formations differ very slightly, if at all, within Western Australia, and are more typical of inland localities. The only distinctive halophytic formations of the South-West Province are the salt marshes which fringe the estuaries, and the littoral marshes in proximity to the coast. These are flats which are wet or inundated during the winter months, but completely dry in summer, except under unusual conditions. The most characteristic plants are those broadly classed as "samphires," belong to the genera *Arthrocnemum* and *Pachycornia*, halophytic succulents which also occur in the small saline depressions found constellated through the country, and which predominate in such localities. Other Chenopodiaceae are *Suaeda maritima*, *Samolus repens* and *S. Valcrandi*, *Didymanthus Roei* and *Atriplex hypoleuca*, and certain grasses such as *Puccinellia* and *Pholurus*.

The dune plants possess little that is distinctively Australian. It is on the littoral dunes that we find so many palaeotropic groups and species which belong more distinctively to the Eremea. Amongst the former are *Festuca* and *Spinifex*, *Carpobrotus*, *Atriplex cinerea*, *Pelargonium*, *Nitraria Schoberi*, *Cakile maritima* (which is surely a natural immigrant), *Arctotis nivea*, a more recent immigrant, and certain Australian maritime dune species such as *Lepidosperma gladiatum*, *Scirpus nodosus*, *Scaevola crassifolia*, and *Acacia cylopis*. It is interesting to find here, plants which more properly belong to the Eremea, such as *Callitris*, *Exocarpus sparteus*, *Eremophila glabra*, *Alyxia buxifolia*, and *Santalum acuminatum*. These are found in soils which are physically or physiologically dry, and the relationship of the maritime dune vegetation to the Eremea is most interesting, but on the other hand, especially under soil and temperature conditions, the strand vegetation cannot be taken as typical of the country which it fringes. In the northern areas, that is, between the Hill and Murchison Rivers, there is an extensive development of a littoral formation of shrubs or small trees in which certain species of *Acacia* play an important part. To the north the area is rich in lianes, and although the shrubby plants are in close association, there is also a marked development of herbaceous species. Here again is a marked admixture of plants which we regard as being typically Eremean, e.g., *Gyrocarpus*, *Zygophyllum*, *Jasminum*, *Hibiscus*, and *Cienfugosia*, or tropical (*Aphanopetalum* and *Dioscorea*).

(g) SAND HEATHS.

Wherever the soil is of a sandy nature, whether a loose detritus or the more compacted yellow or red sand of the interior, heath-like formations predominate. These heaths vary from typical low heath in the humus soils of the southern littoral, to the taller heaths of the sand of the savannah and sclerophyllous woodland zones and the northern littoral. The shrubs usually vary from 5-1 metre in height, and are often intermixed with small thickets of the mallee type of *Eucalyptus*, *Melaleuca*, or several Proteaceae, but their constitution varies considerably within the various climatic areas, those of the wet districts often merging into swamp formations, while those of the interior and the north usually occupy only the high ground. The most extensive areas of this formation occur between the Hill and Greenough rivers, between the Hutt and Murchison rivers, between Tammin and Bandering, and in the southern littoral between King George's Sound and Israelite Bay. In other places the heath areas, intersected by thickets and woodland, form a broad pattern in the broad zone lying between the 500 and 175 mm. seasonal isohyets.

The heath formation is the real home of the true autochthonous flora, which is exhibited here in endless variety. The most representative families are Epacridaceae, Haemodoraceae, Casuarinaceae, Proteaceae, Myrtaceae, Verbenaceae, Rhamnaceae, and Goodeniaceae. On its broad mosaic pattern we are able to delineate with fair exactness the limits of the Epacridaceae, and such genera as *Anigozanthus*, *Conostylis*, *Drosera*, *Isopogon*, *Petrophila*, *Conospermum*, *Lambertia*, *Banksia*, the various genera of the Chamaelauceae, *Kingia*, *Xanthorrhoea*, *Calectasia*, and a large number of plants which represent the autochthonous element.

Characteristic of the heath formations is the development of dew, even in the summer. When the formations of the heavier soils are quite dry in the early morning, a heavy moisture between the months of November and March characterises the heaths, even to the limits of the South-West Province. Another characteristic is the erect or erect-spreading ericoid type of leaf, and this, together with the erect branching of the shrubs, causing an open fabric of the constituents, results in a high insulation. Several plants possess, as a protective measure, a strong development of corky tissue at the base of the stem. This is particularly noticeable in several species of *Boronia* and *Eriostemon*.

In contrast to the plants of the heavier soils, the heath shrubs possess very deep rooting systems. It is not uncommon to find shrubs less than 15 cm. high with a root system extending to a depth of over 60 cm. Most of the plants have a strong primary vertical with deep horizontal secondary roots, the tap-root being as a rule remarkably strong, with a fibrous cortex.

While the contour of the heath vegetation remains more or less uniform, a number of species usually occur which rise much above the general level. Several species of *Grevillea*, *Xylomelum angustifolium*, *Hakea*, *Banksia*, and *Actinostrobus* are familiar examples. They either occur in small groups, or may be found in isolation, standing like sentinels on the heath profile. Otherwise the heath is very uniform in the height of its component shrubs. Some of the heath species, especially the Rhamnaceae and the Epacridaceae bloom before the advent of the winter rains, for example, I have seen *Leucopogon* and *Cryptandra* in full bloom at the end of April at the end of the long dry summer. On the other hand, due perhaps to the beneficial influence of the dews, certain heath species bloom in the height of summer. *Verticordia* and *Conospermum* are notable in this respect, and it should be remembered that the glorious *Nuytsia* which is so aptly named *floribunda*, and which flings its golden wealth abroad in both coastal woodland and sand-heath, is a true psammophyte, and most abundant on the low open heaths between Esperance and the Oldfield river.

Amongst the heath plants one observes as in no other formation except the swamp-yaite woodland, a remarkable development of plagiotropism. The most notable examples are the extraordinary species of *Banksia* of the series Prostratae which occur all along the southern heaths between King George's Sound and Cape Arid. Their subterranean stems radiate to a diameter of over four metres, the isolated inflorescences and floral leaves of some species appearing as isolated plants. Other notable examples are the species of *Eremophila*, *Leschenaultia*, *Astrolooma*, *Scaevola*, *Hibbertia*, *Acacia*, *Grevillea thrysoides* and *G. nudiflora*, *Dodonaea*, and others, including several species of *Darwinia*.

It is in the heath formation that the species of the South-West Province exhibit their greatest epharmonic convergence. Species of entirely different families may appear so alike in form and structure as to be indis-

tinguishable except when in flower. The most noteworthy examples are to be found in *Hibbertia microphylla* and *Leucopogon gibbosus*, between *Acacia* and *Hakea*, or *Acacia* and *Grevillea*.

Finally mention should be made of the taller plants which occur in thicket formation between the sand-heath and the sclerophyllous woodland. As a rule the two formations are separated by a transitional zone in which the mallee *Eucalyptus* takes an important part, or else there may be a close stand of *Melaleuca*, especially *M. uncinata*. This latter species cannot be said to be typical of any distinctive formation. It may occur fairly extensively in the granite soils, especially in areas where the granite has been kaolinized ; it may separate the heath from the formations of psammophytic halophytes, or it may stand as a buffer between the woodland and the heath, when its character changes according to the nature of the soil. Typically the heath merges into a band of dwarf *Melaleuca* which receives here and there a few psammophilous species of *Eucalyptus* ; gradually the mallees become more prevalent, until finally from an association of mallees we pass into the open woodland.

3. THE EREMEAN PROVINCE.

The Eremean Province is, floristically and ecologically, the most impoverished of the three provinces. Possessing no distinctive elements of its own, its flora is derived from elements of the neighbouring provinces, chiefly from those groups sufficiently plastic to permit of epharmonic moulding. It is thus a comparatively young flora in which the outstanding characteristic, a marked evolutionary epharmonic convergence, has been made possible by the plastic nature of the indigenous species and their capacity to adapt themselves to a changed environment. Its permanent elements are those sclerophyllous species which have to fight for existence against a hostile environment, while its herbaceous elements are either ephemeral, or markedly xerophytic in structure.

In its evolution the whole constitution of the Eremean flora is a picture of active epharmosis, resulting in an area of remarkable uniformity of contour and form which is in keeping with its climate. It extends in a practically unchanged condition from the north-west coast to the Darling River, and almost to the south coast, with but little change in its floristic composition, and its formations are edaphic rather than climatic, for climatically it is only the increasing aridity experienced as we travel towards the arid heart of the continent that affects to any extent the density and stature of its component species.

An interesting feature of the Erema is the part played by the psammophytes. Wherever the soil is sandy we find a return of the autochthonous flora of the south-west, or at least its hardy psammophilous representatives. This peculiarity can be studied in various localities. In the red sand of the Anketell district we find an "island" of south-western forms—*Labichea*, *Thryptomene*, *Cryptandra*, *Calythrix*, *Gastrolobium*, *Brachysema*, *Pityrodia*, *Loudonia*, *Monotaxis*, *Eriostemon*, and *Xanthorrhoea*, etc. The same thing applies at Comet Vale, where the Mulga country impinges on the heath ; here are certain localised endemics, including certain Myrtaceous plants of the Tribe Chamaelauciae, with *Newcastlia* and *Lachnostachys*. Even in the north, between the Fortescue and Ashburton rivers we find *Verticordia grandis*, *Pileanthus*, *Pityrodia*, *Calothamnus*, *Commersonia*, *Diplopeltis*, *Adriana*, and *Calythrix*, while *Cyanostegia* extends to Roebuck Bay. These isolated areas of sand in which the autochthonous flora is predominant, forming as it were outposts of the south-western flora, suggest that it is in these places that the

old pan-Australian element is maintaining its last stand, or on the other hand, and more probably, that it is in this environment that as an unmodified invading element the autochthonous flora finds conditions suitable to its development. I have previously pointed out that most of the plants of the Autochthonous element are psammophytes.

On the other hand, the loamy and alluvial soils of the Eremaea provide the environment for the hardier species of the Palaeotropic Element. The species of *Sorghum*, together with many other palaeotropic grasses, *Acacia Farnesiana*, *Clerodendron*, the Cucurbitaceae, etc., have established themselves in regions far south of the Tropic of Capricorn. For example, *Acacia Farnesiana* occurs as far south as the Murchison River, and *Ficus* occurs as a lithophyte as far south as Mount Margaret.

THE FORMATIONS.

(a) THE SCLEROPHYLLOUS WOODLAND.

The sclerophyllous woodland of the Eremaea is the same in composition as that of the marginal areas of the South-West Province, differing only in the increased paucity of its undergrowth, and in the floristic composition, as well as in the importance of grass, which increases as warmer temperatures are experienced, while the increasing aridity results in greater numbers of Chenopodiaceae in the open spaces. A brief description of the formation has already been given. It is sufficient to say here that the formation extends furthest in saline and loamy soils, the most inland locality being found near the shores of Lake Darlot, where a *Eucalyptus* woodland of *E. Dundasi* and *E. Lc-Soueffii* occurs in saline soil with a ground covering of Chenopodiaceae, Myoporaceae, and Malvaceae, including the remarkable *Plagianthus Helmsii*.

(b) SALSOLACEOUS SHRUB STEPPE.

To the east of Israelite Bay and Balladonia, there is an extensive area known as the Nullarbor Plain, the limestone soil of which supports a vegetation averaging 50-100 cm. in height, consisting chiefly of Chenopodiaceae, *Myoporum*, *Eremophila*, and other low shrubs which are distinctly Eremean in character. During wet periods a remarkable herbaceous growth quickly appears, to die again when the soil moisture is exhausted. I have no first hand knowledge of the formation, but apparently it is developed extensively in South Australia. Its ephemeral herbaceous species are mainly Compositae and a few annual grasses.

(c) MULGA BUSH.

The mulga bush covers a greater part of Australia than any other single formation. The conditions limiting its distribution to the south are only imperfectly understood, but the line corresponds roughly to the Meyer Ratio isopleth of 25 inches, and more approximately to the 80° F. mean isotherm for January and February (the end of the dry season). There is also a certain change in the soil which may be the result of climatic factors, and a certain pluvio-thermal significance in this line, since to the south, with a slightly increased rainfall, the wet season extends from March to August, while in the mulga bush, the six consecutive wettest months are January to June. The annual rainfall falls short of 950 points. Little more can be said of the climatic control except that the mean temperature for the four wettest months is in excess of 18° C., while for the sclerophyllous woodland to the south it is less than 18°. Unfortunately there are few meteorological stations within the area, and only two near the boundary, and thus our knowledge concerning the controlling climatic factors is very limited. The line of demarcation is,

however, remarkably well defined. One crosses it at Goongarrie to the north of Kalgoorlie ; it runs exactly past Mt. Singleton, very close to Mt. Jackson, and it is intercepted again between Pindar and Wurarga. Exactly what happens to the east of Goongarrie is not definitely known, but the southern boundary reaches the coast at Shark Bay. Travelling towards the mulga bush we find that the *Eucalyptus* shrubs and trees become more and more scarce, except in the sand, the species of *Acacia* become more prominent, and finally we enter into a region where the genus becomes dominant, the species being shrubs 3-7 metres high, with rigid glaucous phyllodes.

I have already mentioned the fact that the species of the Eremaea exhibit a marked epharmonic development. *Acacia* gives us a case in point. The common jam tree of the south-western savannah woodland (*Acacia acuminata*) has green phyllodes 7-25 cm. long and 4-7 mm. broad, in the typical form ; in loamy soils it develops as a shrub with narrower phyllodes, but still green and flat. As we approach the mulga country, this shrubby form becomes more and more common in the loamy soils, its phyllodes gradually becoming narrower with the increasing aridity, until finally, in the mulga bush it merges into *Acacia Burkittii*, with terete or only slightly flattened phyllodes, and smaller flower spikes. This gradual transition may be studied anywhere between Mullewa and Meekatharra ; at the former station we have typical *A. acuminata*, and at Meekatharra in the loamy soil of watercourses we have typical *Acacia Burkittii*. A similar graduation may be seen between *Eucalyptus pyriformis* and *E. Kingsmillii*. The same holds true for a number of plants, and this is nowhere more evident than in the genus *Eremophila*, particularly between *E. Gilesii* and *E. foliosissima* ; but numerous examples could be given, and the above should suffice to illustrate the point. This epharmonic development is indeed carried out to such an extent in the Mulga country that ultimately, amongst the woody plants only two or three types of growth form and foliage remain. In general, with but few exceptions, the broad-leaved plants are either covered with a close indumentum of stellate or floccose hairs, or are heavily coated with resin. The glabrous leaved shrubs have narrow erect or pendulous leaves which all assume the same form, and the branching habit is much the same throughout.

The *Acacia* species are of three types : Those with pinnate leaves inhabiting the watercourses ; those with green pungent phyllodes of the "Curara" type with a similar habitat ; those with erect or drooping rigid glaucous phyllodes—the true "mulga" plants—and those with pendulous flat green phyllodes, e.g., *A. quadrimarginea*.

Next in importance to the species of *Acacia* are the species of *Eremophila*, which number about one hundred. No other genus in the province exhibits such diversity of form. The large handsome blossoms are short-lived, and in many species the calyx becomes enlarged and coloured after anthesis. While some conform in their growth form to the general plan, others are widely branched with large resinous leaves. They remain of enormous physiognomic importance within the formation, and occur mostly in the sandy or stony soils, the genus being perhaps the most typical of all Eremean genera.

The distribution of *Eremophila* is interesting. By far the greater number of the species of this genus are found in Western Australia, and although some are plants of the heavier soils, by far the greater number are psammophytes or lithophilous. This together with the fact that the genus is fairly well represented in the littoral areas of the South-West, and also on the south and western heaths, suggests that it has developed from this pro-

vince, or at any rate from a littoral source. Their development suggests that as halophytes they have been equipped for the dry and saline tracts of the Eremaea. Indeed, it may be said that they are principally developed in the Eremaea as psammophytes or halophytes.

Together with *Eremophila*, the genus *Cassia* assumes considerable physiognomic importance in the Eremaea, being developed most extensively in the sandy areas. The development of an indumentum of felt has enabled these plants to endure extreme aridity without any loss of leaf-surface, a fact which is curious when it is considered that the only species of the genus which has invaded the marginal areas of the South-West Province, has its leaves reduced to two or three terete segments. The desert species—*C. desolata* and *C. Sturtii*—are examples of the plants which, endowed with a thick felted indumentum, have, without any reduction in leaf-area been not only able to exist here, but become increasingly important in the more arid regions of the north, extending into the steppe formation.

Perhaps the most remarkable tree of the Mulga country, and of the Eremaea generally, is the Kurrajong (*Brachychiton Gregorii*). This tree, which attains to a height of seven metres, has the spreading branches and dense leafy crown of *Platanus*, which it somewhat resembles; its large bright green broad leaves are partially or completely deciduous, and its trunk and roots store water which is used in periods of excessive drought, at the time when leaf-fall takes place. It is an alien aristocrat of the Eremaea, quite unlike any other growth form, and while of undoubtedly palaeotropic origin, has extended as far south as temperate latitudes. It is still in evidence at Westonia, Bullabulling, and at Lake Lefroy near Widgiemooltha.

The number of palaeotropic elements amongst the undergrowth of the mulga bush is surprisingly large: examples are *Breweria*, which extends also into the northern parts of the South-West Province, *Tecoma*, *Justicia*, *Plectronia*, *Pomax*, *Hibiscus*, *Gossypium*, and amongst the lianes, *Marsdenia*, *Porana*, and *Pentatropis*. They are found principally in the shade of the larger species, often clustered round the stems (especially *Ruellia*), or in stony soils.

Most, if not all of the woody elements of the mulga bush, possess seeds remarkable for their longevity. The seeds of some species of *Acacia*, for example, may lie in the soil in a viable condition for upwards of a century—a factor of considerable importance when we consider the capricious nature of the rainfall and the periodic desiccation by drought which characterises the region. In addition, the species of *Acacia*, unlike those of more favoured regions, produce their blossoms shortly after rain falls. Blossoming may occur twice in the same year, or on the other hand, it may be withheld for a number of years. There is thus no regular flowering season for the species of this genus, while on the other hand, the species of *Eremophila* and *Prostanthera*, *Dodonaea*, etc., appear to have prolonged regular seasons. In fact, the species of *Eremophila* bear at least some flowers almost throughout the year.

The wealth of the ephemeral flora of the mulga country is one of the most remarkable of its characteristics. The formation is typically one of widely spaced shrubs with bare exposed soil, but after suitable winter precipitations the whole area is carpeted with an amazing wealth of annual herbs which cover it with colour. These consist mainly of Compositae: wide stretches of *Helipterum splendidum* and *Cephaelipterum Drummondii* in the alluvial soils appear from a distance like patches of freshly fallen snow; the sandy areas are carpeted with *Calandrinia*, *Erodium*, the handsome rose-pink *Velleia rosea*, purple *Bellida*, the gold of *Helipterum Battii* and *H. Charsleyi*,

and the violet and white of *Calotis*, *Brachycome*, and *Erodiocephalum*, while the masses of the vetch-like *Swainsonas* intermingled with the whole provide a herbaceous floral wealth unexcelled in any other formation. This brief pageantry continues only for a few weeks ; two months later there remain only the withered remains of stalks as evidence of this.

On the other hand, the summer rains call into being an almost equal richness of grasses and *Trichinium*, the former consisting mainly of short-lived annuals such as *Aristida* and *Chloris*, *Brachiaria*, *Setaria* and a few others, at the same time reviving the dormant stocks of the perennial species such as *Eragrostis*, *Neurachne*, *Triodia*, *Plectrachne*, and *Eriachne*. *Stipa*, the principal representative of the sclerophyllous woodland, is entirely absent, and *Amphipogon* does not extend far into the formation from the south. The mulga-bush formation exhibits this biannual succession to a degree not observed in any other formation in Western Australia. In both cases it is short-lived, without a sufficient rainfall it does not occur, and for years no annual species may appear.

The true mulga (*Acacia ancura*) is the most common species in the mulga bush, and its range extends throughout the formation, or practically so. It is most typically developed in those soils with a hard subsoil close to the surface ; in the lighter deeper soils it becomes scarce or entirely disappears, and its place is taken by *Acacia linophylla* in the area between the Minilya and Murchison districts near the coast, while farther north, between the Minilya and Fortescue Rivers, *Acacia xiphophylla* assumes a dominant role, but even here, in the hard-pan soils, or in clay depressions, *Acacia aneura* reappears, and once more becomes dominant to the east of Mount Bruce in the upper Fortescue watershed.

Over very large areas of flat or undulating country the *Acacia* species which dominate the formation provide a uniformity of contour and physiognomy to which the formation owes its name. The various species so closely resemble each other even when in flower, that it is often impossible to determine accurately the component species, unless pods and seeds are available. The species are so plastic, that it is probable that ultimate research will disclose fewer species than those already described, since the so-called species appear to merge into each other. The landscape resembles a flat or rolling sea of a dull grey-green, relieved only by the rocky eminences, and the scattered salt-lakes which glisten in the sun.

The stony hills and " breakaways " provide some relief from this monotony, for here we find a more varied flora. Here we find the bright green masses of *Dodonaea filifolia* covered with crimson hop-like fruits, the green-leaved *Plectrantha*, *Santalum*, *Hibiscus*, *Eriostemon*, *Grevillea extorris*, an occasional *Melalcuca* or *Thryptomene*, and the green-leaved *Acacia quadrimarginea*, mixed up with brilliant masses of *Eremophila*, and the large-spiked *Trichinium rotundifolium*, with several herbaceous species of the same genus, together with the dense Cupressus-like masses of dull green *Callitris glauca*. The white corky barked *Tribulus platypterus*, with its pale pinnate leaves and yellow star-like flowers adds a bizarre note to this strange assembly in an environment so poor in forms.

(d) THE HALOPHYTIC FORMATIONS.

Throughout the Erema, salt-pans, clay-pans, and the remains of former ancient river systems are scattered. They form perhaps the most striking physiographic feature of the landscape, appearing intensely bright because of the reflected light of the salt crystals of their dry surfaces, because of the remarkable mirage, and lastly because of the distinctive grey vegetation which

covers their broad margins. In this vegetation the Chenopodiaceae assume the leading role. Species of *Atriplex*, *Bassia*, and *Kochia* cover the ground with their lowly forms, relieved here and there by the more halophytic members of other families, which form a striking contrast in colour—the green of *Hakea Preissii* and *Casuarina lepidophloia*, although the latter is green only by comparison, for its branchlets are more or less glaucous. The larger shrubs are mainly species of *Eremophila*, such as *E. pterocarpa* and *E. floribunda*, both with dense rounded crowns of light grey foliage. Only where the soil has been heaped into small rises do we find any relief from the drab colour scheme, and here we find the purple-spiked *Triehinium exaltatum*, stretches of pink-flowered *Frankenia*, dense masses of halophytic *Swainsona*, with *Senecio* and *Peplidium*, while in the south we occasionally find dense stretches of rose-flowered *Carpobrotus*. In the salt-pans of the mulga bush we find two halophytic Malvaceae—*Plagianthus microphyllous* and the remarkable *P. Helmsii*, the latter with a candelabra-like habit and densely packed clusters of leaves and flowers, looking from the distance like a *Euphorbia*. The hardy halophytic grasses are species of *Eragrostis*, especially *E. falcata* and *E. lanipes*, which intrude sparingly into the area dominated by *Bassia* and *Atriplex*. The margin of the surface salt, beyond which no plant life extends, is usually indicated by a band of the green samphires which always remain as the last rampart of the halophytic association.

(e) THE TRIODIA STEPPE.

Grass steppe occurs on the red sandy soils of the Eremean Province. It is most typically developed in the areas which receive a summer rainfall, but in a modified form it extends into the middle zone of the Erema where the highest precipitations occur between March and June. It is entirely absent from the May-August rainfall zone except in a very impoverished condition near Coolgardie, to the east of Mount Holland, and near the Fraser Range, where the presence of *Triodia* tussocks in the sand-heath formation render it peculiar. It is, however, exactly in these marginal sand-heaths that the March rains are very important.

Speaking generally, the *Triodia* Steppe is a formation controlled by summer precipitations and a sandy soil. It is the red sand that supplies its peculiar edaphic requirement, except in the tropical north, where it occurs in the stony soil of the Nullagine series, as for example the mountains and escarpments of the Hamersley Ranges and the Hann Plateau in Kimberley.

The predominant genus is *Triodia*, comprising about a dozen species. This grass forms dense tussock-like masses which usually average about a metre in diameter, and may be cushion-like, dome-shaped, or conical. They are very rarely contiguous, but are separated by narrow patches of bare sand, and their growth continues peripherally, until in old plants the tussocks may be as much as four metres in diameter, ultimately tending to become annular as the centre dies out. Frequently, as a result of fire, these annular growths are interrupted, and from small nuclei, fresh tussocks are again formed, which in turn repeat the process. This is particularly true of *Triodia Basedowii* and *T. irritans* in which, in the old plants, the progressive annular development of the tussock results in some overlapping of the rings, causing a loose network of living culms with dead centres, or the centres may be represented by areas of bare red sand. The leaves of all species are pungent-pointed, a characteristic that renders the plants forbidding.

The formation extends to the coast between Onslow and the Eighty-mile Beach; but is otherwise absent from the littoral. From the north-west coast

it extends almost uninterruptedly through and around the Hamersley Range and dominates the northern part of the Eremean Province between the Mulga Bush formation and the savannah formations of the north. In some places it intrudes into the Mulga Bush country where the red sand provides the necessary environment, but here it loses much of its character by reason of the presence of the mulga trees and other shrubs. In its typical form, the *Triodia* Steppe is either entirely devoid of trees and shrubs, or there may be a few isolated trees, such as *Acacia pryifolia* near the north-west coast, or scattered Eucalyptus trees in the interior, or some admixture of *Eremophila* and *Cassia*. There are large areas to the north-east of Wiluna, and east of the Carnarvon Range, where, as far as the eye can see there is nothing but *Triodia*, unrelieved by any shrub or tree. It is only under the more favourable conditions of higher rainfall towards the Northern Province, that trees become relatively important, and the steppe formation merges into the savannah, and other grasses compete with *Triodia*, e.g., *Eulalia*, *Chrysopogon*, and *Eriachne*. Before reaching the Fitzroy River it merges into the Pindan country, in which *Acacia* becomes predominant.

Just as to the north it takes on something of the characteristics of the savannah and the Pindan, so to the south, in the Mulga formation, the influence of the winter rainfall causes some local alteration to the physiognomy of the steppe by the addition of shrubs and trees, and the formation receives to some degree the addition of the ephemeral winter flora which characterises the Mulga country. The steppe formation remains, however, a formation restricted to the Nullagine rocks and the red sand, and nowhere is it found away from this soil type, neither does it flourish in the absence of summer precipitations. The drier the conditions, so much more does *Triodia* become dominant, until it enters into the true desert.

(f) THE DESERT.

While, as its name would imply, the whole of the Erema conforms with the broader definition of what ecologists term desert, there is an area close to the centre of Australia which complies with desert in its more limited sense. The extreme aridity of the country, the absence of any permanent surface water, the high annual mean temperature, and the extreme diurnal range, as well as the paucity of the vegetation, are all conditions characteristic of deserts in other parts of the world. This tract, in Western Australia, lies between the latitudes of 20° and 25° , and extends eastwards of longitude 122° as far as longitude 132° .

For our accounts of this country we have to rely largely on the published descriptions of the few intrepid explorers who have penetrated the region. These accounts differ to some extent ; some state that there is no desert in Australia, meaning that there are no large areas of bare sand ; others speak of it in unmistakable terms. The fact that no botanical investigations have been made, renders a true conception somewhat difficult.

In general, the region consists of large areas of sand ; sandstone cliffs mark the escarpments of plateaux which are either sand or gibber-plains, while there are depressions of sandy loamy soil. But it is the red sand that prevails, either in the form of undulating country, or heaped into long ridges or dunes which have in general a meridional trend, or bear in a N.N.W.-S.S.E. direction. These dunes or ridges are either quite devoid of vegetation, or are populated by sparse *Triodia* and a few harsh xerophytic shrubs, while in the trough-like depressions between the ridges there are sparse dwarfed trees and shrubs ; on the other hand there are extensive undulating areas of bare wind-

eroded sand, and gibber-plains on which there is no vegetation of a permanent kind. The only trees met with are in the depressions or at the foot of the escarpments, the most common being *Hakea lorea*, the desert sheoak (*Casuarina Decaisneana*), *Eucalyptus gamophylla*, and *E. setosa*, the two last-named rarely exceeding 10 or 12 feet in height. A few plants of mulga occur here and there in the depressions, e.g., *Acacia sibirica* and *A. Kempeana*, while in the heavier soils are a number of Chenopodiaceae, such as *Kochia*, *Bassia*, and occasionally *Atriplex*. Following adequate precipitations, an ephemeral flora is born, much resembling that of the savannah and Mulga-bush country, but it disappears after completing its brief life cycle.

The sand ridges are usually scantily clothed with shrubs, amongst which *Crotalaria Cunninghamii*, *Newcastlia*, and *Duboisia Hopwoodii* are the most common, while on the flat sandy intervening country are occasional shrubs of *Hakea rhombalis*, *Grevillea eriostachya* and *G. juncifolia*, *Calothamnus*, *Dicrastyles*, *Thryptomene Maisonneuvei*, *Dampiera*, *Petalostyles*, *Hibiscus pinonianus*, *Brachysema Chambersii*, *Sida* and *Acacia*, *Cassia desolata*, and *Micromyrtus*.

It is interesting to find here such plants as *Dampiera*, *Brachysema*, *Calothamnus*, *Thryptomene*, and *Micromyrtus*. They are all local endemics derived from a south-western stock, and are psammophytes equipped for a hostile environment. *Crotalaria*, *Hibiscus*, and *Petalostylis* are of northern origin, and their appearance may seem strange, were it not for the fact that all possess an indumentum which enables them to thrive far removed from their main centres of distribution. One should perhaps in this connection mention *Gossypium Sturtii*, although we do not know whether this species is a psammophyte, or confined to rocky gullies.

The only endemic genus of the true desert is *Newcastlia*, which through *Heniophora*, *Lachnostachys*, and *Dicrastyles* exhibits a certain affinity with the South-West Province, and once again illustrates the fact that it is the psammophilous elements of the south-west which have not only exceeded the boundaries of the South-West Province, but have been able to create new forms in an arid environment.

As the gradual process of continental desiccation progresses, so also is the desert extending. Under the influence of the prevailing winds it is gradually encroaching upon its neighbouring formations, thrusting here and there into the Triodia Steppe, and while it is extending to the coast in the vicinity of the Eighty-mile Beach, another arm of the steppe is extending along the Tropic of Capricorn to the coast, in the vicinity of the Ashburton River. There can be little doubt that the Hamersley district is threatened with an Eremean invasion which will, sooner or later, completely overrun it.

VIII.—EPHARMOSIS AND GROWTH FORMS.

Just as the species is the unit of the systematic botanist, so is the "vegetation form" the unit of the ecologist. To quote Warming: "Every species must be in harmony, as regards both its external and internal construction, with the natural conditions under which it lives; and when these undergo a change to which it cannot adapt itself, it will be expelled by other species or exterminated. Consequently, one of the most weighty matters of ecological plant-geography is to gain an understanding of the epharmony of species. This may be termed the plant's *growth form* in contradistinction to its systematic form." It reveals itself specially in the habit and in the form and duration of the nutritive organs, but shows to a less extent in the reproductive organs."

A well-known result of epharmosis is the convergence of systematically removed types. Examples are to be found in certain plants, such as between *Ceriops* and *Ægiceras*, *Acacia* and *Hakea*, *Acacia* and *Daviesia*, *Darwinia* and *Pimelea*, *Siegfriedia* and *Darwinia*, *Hibbertia* and *Leucopogon*, *Hibbertia* and *Pultenaea*, of which some species of one genus so closely resemble species of the other genus that, growing together they can only be separated when in flower. The careful climatic grading of the Western Australian flora has resulted in numerous epharmonically moulded species and forms which attain to their highest development in the *Eremaea* where the epharmonic convergence reaches a climax in which the species conform to few general growth-form types.

GROWTH FORMS.

1. TREES AND SHRUBS.

Trees and shrubs make up the greater part of the vegetation of Western Australia. Their importance is, however, greater in those areas dominated by the winter rainfall—summer drought climate than in those areas in which summer rainfall prevails. It is especially true of the South-West Province where the preponderance of shrubs is overwhelmingly great when compared even to trees.

One of the outstanding characteristics of the forest and woodland formations of South-Western Australia is the paucity of the tree species growing in intimate association, with one of them assuming the dominant role. This is particularly true of the karri, jarrah, and tuart forests where, subject to edaphic changes, the dominant tree suffers few or no competitors. For example, the tuart forest remains essentially pure: the jarrah tree almost so, except where the lateritic soil changes to sand, marri (*Eucalyptus calophylla*) assumes prominence, while clay soils give rise to trees of wandoo. There is, perhaps, nothing comparable to this uniformity of the species of the *Eucalyptus* forests and woodlands if we except the coniferous forests of the northern hemisphere. The savannah (temperate) woodland formation is more mixed in its arborescent species, and *Acacia acuminata*, *Eucalyptus loxophleba* and *E. redunca* var. *elata* become social species. It is only in the eastern sclerophyllous woodland areas that we find any real mixture of the tree species, and although all are species of *Eucalyptus*, we find a considerable mixture of species. In the Eastern goldfields areas we find many such examples: the trees may very closely resemble each other, such as *E. Flocktoniae*, *E. Brockwayi*, *E. transcontinentalis*, *E. salmonophloia*, which are very much alike both in habit, bark, and foliage, or dissimilar species may grow in intimate association. Between Widgiemooltha and Norseman, for example, or between Mount Holland and the Bremer Range, one frequently finds as many as fifteen different species growing in association under similar edaphic conditions.

In the northern Province it is quite otherwise, for in the monsoon woodland we find trees of different families, of very diversified growth-forms, even deciduous and evergreen, growing together. It is possible to find *Callitris*, *Eucalyptus*, and *Livistona* assuming equal importance and growing together in a woodland association.

While *Eucalyptus* remains dominant in the South-West, *Acacia* assumes the dominant role over the broad area of the *Eremaea*, and in the Northern Province, especially in the Kimberley district, there is no dominant genus amongst the trees if we except the basaltic savannah, where *Eucalyptus* becomes again dominant. The *Eucalyptus* trees of the north however, remain highly diversified in both growth form and foliage. The dense spreading

crown and large horizontal leaves of *Eucalyptus clavigera* and *E. setosa*, for example, are quite unlike those of any *Eucalyptus* of temperate latitudes, and closely resemble *Angophora*. The same may be said of the curious *Eucalyptus brachyandra* with its widely spreading branches and deciduous foliage.

Quite otherwise is the state of things in the South-West Province and the Eremaea. Here we find amongst the species of *Eucalyptus* much the same leaf form, and, with the exception of *Eucalyptus calophylla*, *E. ficifolia*, and *E. haematoxylon*, trees with the same shape of leaves, and a light crown. In the comparatively wet forest areas there is development of spreading branches, but when we travel eastwards to the woodland formations we find, first typically exhibited by the swamp yate and the York gum, a growth form which becomes the dominant form throughout the savannah woodland, the sclerophyllous woodland, and the mulga bush. Not only is this form common to the trees, but it becomes important in the shrubs also. It is perhaps most typically represented by the jan tree (*Acacia acuminata*), but is so consistent both in *Acacia* and *Eucalyptus* throughout the drier areas, that a description of *Acacia acuminata* will suffice. In this growth form, which I shall refer to as the *Infundibular* growth form, the stem, by a system of repeated upward branching, produces a multiplicity of branches and twigs, all attaining more or less the same height, and resulting in a flat or convex dense crown with a light covering of leaves. Seen in lateral profile it resembles a funnel with a convex apex, the branches and branchlets leafless except at the summit. Sometimes the crown is proportionately small compared with the height of the tree, especially in large morrel trees (*E. longicornis*) in the eastern districts. Whereas in *Eucalyptus* the foliage is pendulous, in *Acacia* it is usually stiff and erect.

Amongst the shrubs we find the same infundibular growth form in many plants, notably in Myrtaceae and Myoporaceae, e.g., *Melaleuca uncinata*, *Eremophila interstans* and its allies, and in *Verticordia*. *Verticordia Brownii* offers an excellent example. This plant, known as the "cauliflower bush," has its dense convex surface so closely packed with white blossoms that no interstices are formed, and no leaves are visible. The axillary opposite branchlets are richly developed, resulting in annually produced dense strata of leafy shoots which, viewed laterally, appear as a series of superimposed dense umbrella-like corymbs separated by longer internodes. The flowers are densely congested in the uppermost axils, forming a compact floral mass ; the leaves subtend the pedicels, and usually persist for a second or third year, thus providing a leafy substratum. The richness of the branching is remarkable, and the lower strata consist of the dead remains of branches, the further growth of which has been prevented by the overshadowing of the terminal canopy. The whole resembles an umbrella in which the surface is annually renewed, and each year's successive vegetative growth is plainly discernible.

As an adaptation to withstand the desiccating action of dry winds, this growth form is obviously most effective, since only a minimum of the leafy area is subjected to the action of such winds. It is associated with an erect, or pendulous foliage, so that a great number of leaves can be carried without overlapping. It is usually the uppermost stratum of the crown which carries leaves, and a superimposition of the leafy crown is very rare. That this habit is not due to photophily, as has been claimed, is suggested from the fact that it is most highly developed in the Eremaea on the loamy soils where the plants are widely spaced. This growth form is predominant in the Eremaea, where sometimes the epharmonic convergence is carried out to the extent that it is often impossible to distinguish plants of different families when not in blossom ; it is not developed in those plants which possess an indumentum of

felt or hair, or only to a very slight extent. It reaches its epharmonic climax when complete aphyllly is secured, as in *Casuarina* and *Acacia*, and the genista-like forms of *Eremophila scoparia* and *Calycopelus Helmsii*.

Occasionally in the mulga-bush we find a different growth-form adapted to withstand the action of dry winds. This is the erect-stemmed, horizontally branched form which is typical of *Acacias* of the *A. Grasbyi* and *A. sibirica* type. The simple stem is widely branched with horizontal branches which are again repeatedly horizontally branched to form flat superimposed layers. The lateral outline is thus a series of horizontal planes of leafy twigs bearing short erect pine-like foliage. It employs less wood than the infundibular type because of the superimposition of permanent leafy strata, and it is curious that it should be so rare in trees and shrubs of the arid areas. In both this and the infundibular form, the branchlets are abbreviated, a character common to all the woody plants of the dry areas.

While the infundibular growth form leads ultimately to leaf-reduction or even complete aphyllly in its epharmonic development, the widely branched plants of the Eremaea retain their leaves in an unmodified condition. The pinoid leaves usually arise from abbreviated axes and are thus fasciculated, while the broad-leaved plants have relatively long internodes. Such plants retain their comparatively large leaf area by the production of a protective covering of felt-like hairs, densely interlocked stellate hairs, or the provision of a viscid superficial layer of resinous material. No genus so typically affords examples of all types as does the genus *Eremophila*. In the section *Pholidia* we have ericoid leaves; in *Eremocosmos* there is a tendency for the branchlets to assume the function of leaves, resulting almost in complete aphyllly in *E. Dempsteri*; in the Sect. *Eriocalyx* we have flat leaves covered with felted hairs, e.g., *E. leucophylla*, while in *Platychilus* we have large leaves covered with a lacquer of resinous material, as in *E. viscosa* and *E. Fraseri*, while in the Section *Stenochilus* all types are represented. A similar condition may be seen also in *Cassia*, *C. Chatelainiana*, *C. phyllodinia* and *C. eremophila*, *C. desolata*, and *C. glutinosa* respectively exhibiting the same forms.

There is one outstanding example in the Eremaea of a tree that does not conform to the general epharmonic pattern. This is the Kurrajong (*Brachychiton Gregorii*), which maintains a dense bushy crown of bright green soft leaves which appear to be unaffected by climatic extremes. In this respect it stands in the Eremaea as an alien whose relatives populate the monsoon woodland, and its appearance here is certainly strange. It owes its capacity to withstand the aridity because of its water-storing trunk, and its ability to become deciduous in adverse seasons, being the only tree of its kind within the Eremean Province.

The Proteaceae stand in striking contrast to the Myrtaceae and Mimosaceae in that their growth form is never infundibular, and rarely even corymbose. *Isopogon* and *Petrophila*, for example, produce their new shoots close under the terminal inflorescence, resulting in a di- or trichotomous system, the old terminal infructescences becoming lateral, or remaining in the forks of the branches. Occasionally the growth is sympodially developed. *Banksia* and *Dryandra* also illustrate this form.

In distinction to this is the remarkable further development of the stem or branch found in certain Myrtaceae. In *Callistemon*, *Beaufortia*, *Calothamnus*, and *Regelia*, for example, the inflorescence is apparently terminal, but the rachis of the spike continues the vegetative growth which is often already well developed before flowering is completed, and branching usually occurs *immediately above the inflorescence*, and is usually verticillate; the

successive annual shoots can be ascertained by the number of the successive infructescences.

The production of short lateral leafy shoots at the nodes is a characteristic growth form of several Myrtaceae, Dilleniaceae, and Proteaceae, especially in *Hibbertia* and *Dryandra*. This leads to the formation of slender elongated branches or stems densely crowded with abbreviated leafy shoots often bearing terminal flowers. It is seen to advantage in *Hakea ruscifolia*, in *Hibbertia teretifolia*, and in some species of *Dryandra*.

Finally, there are the chamaephytes which develop a marked plagiotropism in their growth. These are mainly the plants which rise but little above the soil, or are so closely pressed against it that they form dense mat-like or cushion-like growths. They are typified by *Astroloma*, *Dodonaea* *Acacia pulviniformis*, *Leschenaultia formosa* and *L. tubiflora*, *Scaevola pulvinaris*, and species of *Dampiera* in the wet clay or sandy-clay soils of the southern woodlands in which *Eucalyptus occidentalis* is the dominant tree. On the sand-heaths of the southern littoral occur *Leschenaultia*, *Scaevola*, *Eremophila* and *Banksia*. In the clay soils of the areas between Norseman and Grasspatch many examples occur in *Acacia* and *Eremophila*, while to the north the chamaephytes are perhaps best developed in the sandy or lateritic areas, *Leschenaultia macrantha* and species of *Darwinia*, together with *Actinostrobus acuminatus* being typical examples. In the case of *Banksia repens*, *B. prostrata*, and *B. Goodii*, the stems are usually covered by the sand, and the isolated flower-clusters in *B. Goodii* appear as isolated plants scattered over a diameter of three or four metres which represents the extent of the branching system. The inclusion of *Eremophila* amongst the chamaephytes once more illustrates the remarkable diversity exhibited by the plants of this genus both ephemerally and floristically. No other genus in Western Australia is more worthy of study from almost every point of view within the study both of ecology and systematic botany.

2. LIANES.

Using the term in its widest sense, the lianes occur in almost all formations in Western Australia, but their number is not large. As one would expect, they are most common in the forest and littoral thicket areas, where *Clematis*, *Kennedyia*, and *Hardenbergia* offer the best examples, and almost complete the total list. On the western plain we encounter in the richer soils three plants which are remarkable because of their restricted occurrence: *Aphano-petalum*, from the Chapman River, *Clematocissus* which extends from the Murchison River to the Hill River, and becomes leafless during the dry season, and finally *Dioscorea*. Their occurrence here suggests that they are migrants from the north, but their absence to the north of the Murchison River is remarkable. In the Northern Province the lianes are mainly recruited from the *Asclepiadaceae*, *Apocynaceae*, *Papilionaceae*, and *Convolvulaceae*. *Marsdenia australis* extends as far south as the southern confines of the mulga-bush formation, while *Glycine* extends much further south, associated with the granite rocks. The other important lianes are to be found amongst the Pittosporaceae, *Billardiera*, *Marianthus*, and *Sollya*, having an extensive distribution through the South-West Province; *Marianthus erubescens* and *Billardiera* alone extending to the boundaries of the Eremaea. *Comesperma*, with two twining species, almost completes the list of southern forms which extend into the interior, although *Kennedyia prorepens* is the sole Eremean form which extends as a psammophyte into the desert. *Cassytha* has a general distribution throughout Western Australia, but is more abundant in coastal than in inland situations. It is almost absent from the far interior, but common in the littoral thickets and the swamps.

3. HERBS.

The perennial herbs are not richly developed in south-western Australia, except amongst the Liliaceae, Haemodoraceae, Droseraceae, Stylidiaceae, Goodeniaceae, Cyperaceae, Restionaceae, and Gramineae. They are mainly characterised by a caespitose or cushion-like habit of growth, or are provided with strong rhizomes, tubers, or bulbs, and are mainly inhabitants of the swamp formations, the granite rocks, or the savannah woodland. The Orchidaceae in general also conform to this general requirement.

An exception to this general rule is to be found amongst the Stylidiaceae, Goodeniaceae, and more particularly amongst the autochthonous Haemodoraceae, which latter especially are mainly psammophytes. Examples are *Anigozanthos*, *Blancoa*, *Macropidia*, *Conostylis*, and *Phlebocarya*. All of these possess strong rhizomes and have either narrow persistent sub-distichous leaves, or their leafy parts wither during the dry summer. A further characteristic is the hairy or woolly indument of their inflorescences, and sometimes of their leaves also. The bizarre colouring of *Anigozanthos* and *Macropidia* has made them famous.

The Liliaceae and Droseraceae on the other hand have hypogeal resting organs, usually corms or bulbs. While their development is fairly high in the south-west, it is relatively low when contrasted with the floras of other lands with a similar climate. It is indeed far short of what one would expect when the almost similar conditions which are experienced in the Cape Province of South Africa are considered. The most diversified habit is exhibited by *Drosera*, which has erect branching forms in *D. gigantea*, rosette-like forms in *Lamrolepis*, and several scendent species in *Ergaleium*. The Liliaceae are both bulbous and fibrous-rooted, or some, like *Stypandra* and *Arnocrinum* have strong rhizomes.

The Cyperaceae are mostly swamp plants, and attain their greatest development in the lower south-west. A few venture into the sand heaths as hard tussocky species, but they are entirely absent from the Eremaea, except as inhabitants of river banks or marshes. They are particularly well developed in the swamp lands of Kimberley.

The Restionaceae, unlike the Cyperaceae, are mainly psammophilous, and are equally at home in the periodically swampy areas, or on the dry sand, where they sometimes assume a position of importance. Most of them are strictly endemic in the South-West Province, but a few, such as *Ecdeiocolea*, *Lepidobolus*, and *Chaetanthus* are more typical of the heath formations extending into the Eremaea. The fact that the dry sand of the interior has produced forms such as this, together with the locally endemic *Hopkinsia* and *Harperia*, illustrates once again the remarkable psammophilous preference of the autochthonous elements.

In the Eremean Province the Compositae become increasingly important, and have been discussed under the chapter dealing with the Mulga Bush. *Calandrinia*, the "parakeelya" of the interior, is another example of a tuberous-rooted perennial which thrives under dry conditions. The species of *Calandrinia* are of wide occurrence in the Eremaea, and in addition to having tubers, the leaves are succulent. Some flower when in leaf; others, like *C. schistorrhiza*, commence to bloom after the leaves have withered, their delicate blossoms defying the dry heat of early summer.

The grasses are of most importance in the areas which receive summer rain. Grass predominates in most of the Kimberley and northern formations, but is also important through a wide area of the Eremaea extending south

to Meekatharra and Sandstone, in the area which receives as a rule some rain from the storms which visit the north-west coast. They are mostly of the harsh tussocky type in the dry regions, but range from the soft-textured species of the black soil plains to the uninviting *Triodia* and *Plectrachne*.

The perennial grasses are dominant in the savannah, the savannah woodland and the steppe. The commonest genera of the tropical savannahs are *Themeda*, *Cymbopogon*, *Iseilema*, *Astrebla*, several genera of the Andropogoneae, including *Eulalia*, *Chrysopogon*, *Bothriochloa*, and *Dicanthium*, which flourish in the red loamy soils, to the many species of the Paniceae and the soft-leaved Triodias of the lighter soils. *Sorghum stipoideum*, the tallest of the grasses is important in Kimberley, in the monsoon woodland, and the sandstone savannah, extending also to the Pindan near Broome. It attains a height of four metres, and frequently possesses prop-like roots from its lower nodes.

An examination of the tropical genera and species discloses the fact that a number of these are native both to equatorial Africa and southern Asia, e.g., *Sehima nervosum*, and a number of others. The number of endemic genera is very small.

The grasslands reach their maximum development on the loamy soils of the northern rivers—the “black-soil plains”—alluvial areas in which the soil is rich in humus. Such areas are to be found on the Lennard, Fitzroy, King Edward, and Drysdale rivers, as well as the Ord River, while there is an extensive area between the Prince Regent and Glenelg rivers. Further south, in the Fortescue-De Grey district, *Eragrostis*, *Eriachne*, *Enneapogon*, and *Aristida* become more important amongst the perennial species, forming in places large areas of open grassland on the alluvial soils. These grasses either occur as scattered dwarf caespitose clumps in the dry season, where, possessed of strong rhizomes and a dense protection of crowded outer dead leaves they are able to survive sustained periods of drought, or the small stumpy base of the plant is the only evidence of life. With suitable summer rains, however, they develop into a dense ground covering intermixed with shorter-lived grasses and other herbs. I have not seen this country under these favourable conditions, but from the impoverished residuum seen in dry years, and the development in the depressions locally known as “crab-holes,” there can be little doubt that under conditions of adequate seasonal rains, these areas present a picture comparable with the South African veldt.

The hardest of all the grasses is *Triodia*, the “spinifex” of the interior, which is the most important element of the steppe, and which is also at home in the desert. *Triodia* must be regarded essentially as a psammophyte, for it is never seen in loamy soils, where its place is taken by *Eragrostis*, *Eriachne*, or *Enneapogon*. Not only has it a general distribution in sand throughout the north, but it has to a great extent overcome climatic barriers, and has extended as far south as Coolgardie, Mount Holland, and the Fraser Range. It is, however, only in the stony or sandy soils of the Nullagine series that it is really at home. Few other grasses are similarly constructed to withstand the climatic extremes it has to endure, and it thrives under conditions too dry for most other plants. The commonest species of the dry steppe, it is also an important constituent of the mulga bush to the east and north, and its prevalence or absence to a great extent determines the limits of the steppe formation. It always occurs in large scattered tussocks, and by a peripheral system of stolons or rhizomes increases its girth until it ultimately extends

over a diameter of over five metres. Fire destroys the aerial parts, and from the periphery a ring-like growth ensues, or this may be broken up into a number of independent plants.

The distribution of the grasses in Western Australia is interesting, since it shows that they fall mainly into two thermal groups—a megathermic group of 63 genera, representing mainly the Paniceae, Andropogoneae, and Eragrostieae, with a number of endemic genera, and a mesothermic group of 17 genera, represented chiefly by the Festuceae, Aveneae, and Agrostieae, with but one endemic genus, *Diplopogon*. There are few genera which are common to both areas—*Neurachne* extends to the north, but is more properly to be considered of southern derivation ; *Triodia*, *Eriachne*, *Eragrostis*, and *Sporobolus* extend far to the south, but must be considered a northern element. The Sections Arundineae, Chlorideae, Zoiseae, and Arundinelleae are exclusively groups requiring a warm summer rainfall, and the Andropogoneae are characteristically of this element also. In the *Stipeae*, *Aristida* is megathermic, while *Stipa*, its southern counterpart, is mesothermic. *Stipa* and *Aristida* are common only to the eastern districts, the former being mainly south-western, the latter northern.

It is important to consider also the requirements and the development of the grass flora in south-western Australia. The grasses here are sometimes of a very restricted habitat. For example, *Tetrarrhena* and *Microtiena* are confined to the forests and woodlands of the higher winter rainfall areas ; *Sporobolus*, together with *Puccinellia*, *Amphibromus*, *Deyeuxia*, *Poa*, *Eragrostis*, *Lepturus*, *Pholiurus*, and *Dichelachne* show a preference for loamy or swampy soils, wet at least in winter ; while *Danthonia*, *Neurachne*, *Amphipogon*, *Diplopogon*, and *Stipa* favour the sandy soils, and attain their greatest development in the southern regions where the summer rainfall is higher than elsewhere. For example, *Danthonia* is not common on the west coast further north than Gingin, while it is fairly common along the southern littoral. *Festuca* finds a suitable environment both on the littoral dunes and the hard loam of the interior.

Apart from the shade-loving or paludal species, the grasses of the south-west appear to favour the granitic soils, and predominate in the savannah woodland which separates the sclerophyllous woodland from the forest. They are most abundant where the summer rainfall is higher than elsewhere (excluding the forest area), and under its influence we occasionally find an intermixing of both northern and southern types, as at Jarramongup and Coolgardie.

In conclusion I must express my thanks to the Divisional Meteorologist, Mr. A. G. Akeroyd, for permission to publish rainfall and other meteorological statistics, also for kindly reviewing the chapter dealing with the climate ; to Professor E. de C. Clarke for assistance in the chapter on geology and soils ; and to Mr. F. M. Bennett for compiling some of the tables which have appeared in the appendix. Finally, I am indebted to Dr. Gentilli of the University of Western Australia, for permission to use his statistics dealing with annual rainfall variability.

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CLIMATIC TABLES.

TABLE I.—MEAN MONTHLY RAINFALL.

(In Points.)

The figures are complete to the end of 1941.

The figures in brackets represent the number of years during which records have been taken. Stations in italics are those recording temperature.

The figures in heavy type represent the six consecutive wettest months.

I.—NORTHERN PROVINCE.

Station.	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Port George IV.	(27)	1,512	1,113	1,001	214	96	75	30	4	6	39	184	765	5,039
Mount Barnett	...	857	701	421	103	21	11	19	9	18	96	419	782	3,457
Kimberley Downs	...	763	573	416	140	35	25	14	3	2	21	96	50	2,194
Beagle Bay	...	646	658	460	233	51	60	41	19	9	14	108	479	2,778
Turkey Creek	(44)	664	672	411	94	23	30	25	9	17	75	199	495	2,714
Wyndham	(55)	739	606	467	82	20	16	16	3	8	44	192	417	2,610
Derby	(56)	735	556	443	142	73	52	24	9	1	6	83	406	2,530
Broome	(52)	648	568	393	115	61	96	20	11	5	3	56	325	2,301
Fitzroy Crossing	(48)	641	512	333	65	29	37	32	5	5	20	90	341	2,110
Hall's Creek	(51)	543	435	291	70	36	26	25	9	15	53	136	322	1,961
La Grange	(51)	435	436	413	95	82	92	32	9	3	3	37	233	1,870
Anna Plains	(34)	342	252	317	117	88	70	29	10	2	4	31	185	1,447
Wollal *	(32)	328	265	239	92	56	97	47	8	4	3	11	146	1,206
Marble Bar	(47)	283	272	221	96	69	104	50	20	3	21	34	142	1,315
Nullagine	(44)	307	219	218	83	66	89	40	27	5	18	60	165	1,297
Hamersley †	(14)	334	250	318	63	57	74	26	21	14	32	67	81	1,337
Condon ‡	(37)	219	249	303	108	73	106	37	18	3	4	7	65	1,191
Port Hedland	(44)	177	221	324	105	113	126	41	39	5	7	2	33	1,193
Roebourne	(55)	202	196	293	140	100	102	57	25	7	3	7	36	1,168
Tambrey	...	255	357	346	113	97	129	64	35	15	8	31	112	1,562
Mill-stream	...	270	316	288	127	92	136	69	27	12	4	31	105	1,477
Whim Creek	(43)	195	277	430	191	98	111	58	26	10	11	19	41	1,467
Red Hill §	(27)	262	309	228	110	83	147	79	29	10	7	19	73	1,356
Bonny Downs	(35)	237	211	189	68	76	76	32	18	6	22	61	136	1,132
Vlaming Head	...	123	261	208	160	108	247	49	49	5	1	4	0	1,215
Bamboo Creek	...	292	226	206	128	78	137	62	28	3	17	47	127	1,441

* Wollal records for 32 years ending 1918.
records for 37 years ending 1927.† Hamersley records for 14 years ending 1925.
§ Red Hill records for 27 years ending 1925.

‡ Condon

II.—EREMEAN PROVINCE.

(a) Northern Zone (Summer rainfall, Dec.-April).

Station.	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Mundaringi	(26)	142	157	204	81	66	75	25	31	16	50	45	129	1,021
Ethel Creek	(31)	170	185	193	87	66	78	27	11	15	29	44	96	1,001
Roy Hill	(42)	162	204	191	90	63	63	36	25	7	17	33	110	1,001
Three Rivers	(27)	125	88	178	75	114	83	36	17	8	20	37	91	872
Mardie	(54)	120	147	171	67	120	115	52	38	7	4	3	26	870
Winning Pool	(44)	135	166	151	60	129	158	83	48	8	7	34	986	986
Wandagee	...	103	166	96	71	106	158	104	36	14	7	6	34	901
Peak Hill	(41)	124	112	170	92	97	116	55	40	17	14	35	68	940
Wiluna	(43)	132	105	142	135	98	84	47	37	17	26	31	84	938
Kathleen Valley	(22)	84	64	168	71	97	60	47	46	10	28	32	78	785
Mt. Sir Samuel	(40)	103	90	157	77	111	82	65	57	21	23	38	77	901
Meekatharra	(33)	137	80	155	93	108	91	64	50	16	18	30	58	909
Nannine	(47)	107	77	132	68	89	95	64	54	22	19	19	35	781
Warburton Range	*	697	182	330	92	43	54	31	7	2	61	112	118	1,539

* Figures for 1941 only.

(b) Central Zone (Summer-autumn rainfall, Mar.-June).

Station.	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.	
Onslow	(56)	85	107	170	99	147	155	77	45	4	2	4	15	910	
Cue	(47)	95	72	102	70	100	117	90	74	28	21	26	56	851	
Mt. Magnet	(47)	94	91	106	62	104	119	95	92	36	25	29	51	904	
Sandstone	(37)	103	71	119	62	108	95	74	87	23	29	37	71	879	
Lawlers	(45)	91	73	124	86	92	88	63	54	22	25	39	60	817	
Youammi	(27)	62	72	107	85	116	92	86	86	27	33	58	62	886	
Doyle's Well	...	104	72	184	78	94	76	50	53	16	34	45	68	874	
Leonora	(44)	81	78	122	80	93	92	61	66	26	28	44	61	832	
Murrin Murrin	(42)	84	72	137	77	100	94	50	66	24	38	59	75	876	
Luxerton	(42)	87	81	143	89	98	83	58	54	31	33	68	74	899	
Morgans	(42)	84	68	139	88	94	75	47	54	28	29	57	54	860	
Yundramindra	(41)	80	71	130	63	111	89	55	69	32	33	54	73	860	
Kookynie	(40)	86	72	129	76	122	98	76	80	33	47	58	81	958	
Menzies	(45)	71	94	98	84	119	109	85	80	34	41	49	66	930	
Davyhurst	(40)	67	79	98	97	127	114	102	78	96	49	63	52	68	1,012
Bulong	(45)	48	71	92	81	109	102	99	59	86	45	63	64	922	
Zanthis	...	55	77	139	89	107	99	59	86	45	63	79	72	973	
Kanowna	(46)	63	66	107	77	113	105	80	94	43	70	58	70	946	
Kalgoolie	(46)	57	65	109	86	112	107	83	95	45	70	56	66	951	
Widgiemooltha	(44)	60	76	118	108	124	113	80	104	59	96	86	71	1,095	
Balladonia	(51)	48	51	99	70	99	93	72	91	68	97	76	67	931	
Ravlinna	(25)	27	43	78	58	68	58	42	58	32	57	58	58	637	
Loongana	...	40	51	65	43	76	56	33	64	25	25	36	68	615	
Eucla	(63)	55	67	87	105	123	109	93	92	74	75	66	49	995	

II.—EREMEAN PROVINCE—*continued.*(c) *Western Zone.*

Station.	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.	
<i>Gascoyne Junction</i>	.... (34)	109	81	153	50	136	119	102	52	43	11	5	22	855
<i>Hamelin Pool</i>	.... (56)	26	50	56	38	126	185	153	75	35	14	15	9	791
<i>Carnarvon</i>	.... (48)	34	63	50	49	153	248	155	80	35	18	7	6	898
<i>Woormorel</i>	.... (43)	44	50	59	46	128	183	135	75	26	17	6	20	789
<i>Shark Bay</i>	.... (48)	34	63	50	49	153	246	155	80	35	18	7	6	898
<i>Boolardy</i>	.... (51)	66	77	99	53	104	145	105	68	16	9	17	31	790
<i>Murgoon</i>	.... (53)	58	59	99	61	110	165	107	79	22	14	18	34	816
<i>Yulin</i>	.... (21)	43	54	79	64	101	145	130	85	29	12	31	27	800
<i>Yalgoo</i>	.... (45)	63	83	106	62	122	179	132	105	45	33	28	41	909
<i>Latham</i>	.... (8)	68	56	82	166	130	206	191	140	30	31	43	29	1,181
<i>Wubin</i>	.... (15)	28	66	63	87	151	232	186	184	59	61	35	23	1,185
<i>Goodlands</i>	.... (20)	43	36	101	89	140	208	154	122	51	50	40	51	1,085
<i>Kulja</i>	.... (9)	32	44	41	84	128	210	183	163	53	70	56	45	1,109
<i>Mollerlin</i>	.... (13)	38	43	48	85	132	204	156	164	55	82	47	42	1,095
<i>Wiatki</i>	.... (10)	50	61	56	80	106	160	176	162	68	77	39	47	1,109
<i>Bonnie Rock</i>	....	77	43	23	34	88	135	161	127	55	57	81	52	933
<i>Mandinga</i>	.... (29)	56	66	81	91	133	189	189	149	98	90	40	58	1,251
<i>Bencubbin</i>	.... (29)	59	78	95	90	136	191	173	152	80	72	38	51	1,214
<i>Mukinbudin</i>	.... (13)	25	40	59	104	120	149	135	141	62	73	61	52	1,024
<i>Kinnunoppin</i>	.... (29)	43	67	97	95	130	185	174	143	81	80	36	42	1,173
<i>Nungarri</i>	.... (37)	45	65	87	82	146	185	195	148	89	79	40	47	1,209
<i>Burracoppin</i>	.... (40)	37	53	86	91	158	182	195	151	88	86	41	45	1,223
<i>Walgoohin</i>	.... (24)	75	70	93	101	135	192	157	135	73	67	48	50	1,196
<i>Newcarrie</i>	.... (30)	43	56	85	80	134	190	163	146	92	88	38	62	1,217
<i>Westonia</i>	.... (26)	39	56	103	84	161	197	189	157	91	88	59	48	1,285
<i>Bullfinch</i>	.... (30)	59	59	97	106	134	150	149	126	68	74	63	62	1,149
<i>Southern Cross</i>	.... (52)	49	57	96	82	138	136	140	116	72	65	52	49	1,052
<i>Marvel Loch</i>	.... (20)	52	53	127	101	138	164	175	145	85	93	69	52	1,255
<i>Lake Varley</i>	.... (11)	104	38	137	85	169	148	169	178	100	141	62	27	1,358
<i>Lake King</i>	.... (12)	82	28	136	68	162	156	176	180	95	147	72	65	1,347
<i>Salmon Gums</i>	.... (20)	99	60	111	99	139	149	133	140	101	117	91	77	1,316
<i>Coolgardie</i>	.... (49)	59	77	95	82	120	114	86	103	56	76	61	67	1,009
<i>Norseman</i>	.... (45)	55	71	89	96	117	114	86	111	72	92	82	72	1,007
<i>Grasspatch</i>	.... (12)	118	49	115	105	152	178	161	180	110	131	138	63	1,511
<i>Eyre</i>	(42)	81	47	89	87	161	164	117	125	88	82	68	59	1,168

III.—SOUTH-WEST PROVINCE.

(a) *Eastern Zone.*

Station.	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
<i>Wubin</i>	.... (15)	28	66	63	87	151	232	196	184	59	61	35	23	1,185
<i>Gabbin</i>	.... (16)	48	61	85	97	128	185	197	210	88	108	55	22	1,307
<i>Koorda</i>	.... (30)	53	81	75	121	184	181	141	82	70	36	46	41	1,125
<i>Wyalkatchem</i>	.... (32)	63	69	87	87	157	235	227	163	100	81	36	40	1,345
<i>Korrellocking</i>	.... (29)	49	60	107	91	156	238	218	169	100	83	45	39	1,355
<i>Trayning</i>	.... (34)	51	63	99	89	135	210	100	153	89	89	41	47	1,266
<i>Kellerberrin</i>	.... (49)	34	47	93	79	166	220	219	174	108	85	43	61	1,329
<i>Doodlakine</i>	.... (31)	36	59	90	85	137	194	192	155	85	93	48	61	1,235
<i>Merredin</i>	.... (38)	40	46	92	84	154	203	213	168	104	89	44	57	1,292
<i>Bruce Rock</i>	.... (27)	51	71	104	86	167	215	215	169	99	98	46	52	1,373
<i>Narembeen</i>	.... (14)	29	33	58	71	145	177	208	180	80	97	53	35	1,166
<i>Kondinin</i>	.... (24)	41	50	90	91	178	203	207	171	106	102	50	42	1,340
<i>Hyden</i>	.... (13)	53	46	91	75	167	174	205	168	82	111	89	59	1,320
<i>Newdegate</i>	.... (16)	73	20	144	78	166	182	212	173	108	132	63	47	1,398
<i>Jarramongup</i>	.... (47)	55	55	120	128	180	177	205	174	149	144	74	70	1,531
<i>Ravenshorpe</i>	.... (40)	76	64	142	126	172	155	180	176	143	156	101	95	1,586
<i>Ongegup</i>	.... (27)	78	61	120	110	201	197	200	172	150	147	80	48	1,561
<i>Hollerton</i>	....	42	35	141	172	134	173	254	251	103	135	41	39	1,520

(b) *Central Zone.*

Station.	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
<i>Ajana</i>	.... (21)	32	37	92	78	213	321	224	175	73	40	24	27	1,336
<i>Yuna</i>	.... (32)	40	59	96	68	190	312	263	181	90	62	30	31	1,421
<i>Mullewa</i>	.... (46)	45	52	78	65	182	267	234	180	91	56	28	30	1,308
<i>Nangatty</i>	.... (38)	46	29	83	80	184	317	270	189	118	68	34	19	1,455
<i>Canna</i>	.... (22)	52	63	138	97	174	306	242	172	86	60	46	49	1,485
<i>Mingenew</i>	.... (40)	32	38	71	81	218	359	318	245	131	81	40	27	1,642
<i>Morawa</i>	.... (28)	60	73	113	88	172	242	225	167	91	64	57	40	1,392
<i>Perenjori</i>	.... (24)	41	72	107	100	173	265	204	187	83	52	46	33	1,343
<i>Three Springs</i>	.... (35)	51	65	78	92	191	318	292	224	112	74	35	32	1,567
<i>Carnamah</i>	.... (53)	45	54	82	84	206	321	279	229	125	73	43	39	1,580
<i>Coorow</i>	.... (30)	45	60	83	95	183	326	283	218	127	82	40	45	1,587
<i>Buntine</i>	.... (26)	51	73	112	84	163	276	219	183	85	71	33	37	1,407
<i>Watheroo</i>	.... (29)	33	56	101	92	217	339	294	221	127	85	33	38	1,636
<i>Dalwallinu</i>	.... (29)	55	74	90	82	162	276	234	190	104	74	53	37	1,421
<i>Milling</i>	.... (11)	60	70	100	103	191	296	253	257	100	73	40	44	1,586
<i>Ballidu</i>	.... (29)	50	57</td											

III.—SOUTH-WEST PROVINCE—*continued.*(b) *Central Zone—continued.*

Station.	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.	
Minnivale	(30)	52	62	91	82	182	254	237	188	105	79	41	43 1,396
Northam	(61)	34	40	78	84	226	323	342	256	151	100	40	37 1,711
Meckering	(44)	28	47	70	86	200	281	293	223	126	97	44	31 1,526
Cunderdin	(28)	43	60	87	87	197	245	264	200	95	104	41	35 1,458
Tammin	(30)	42	48	90	89	164	230	236	176	106	103	45	49 1,378
Beverley	(56)	33	42	68	88	230	320	325	250	157	102	49	24 1,688
Quairading	(31)	43	59	89	82	198	236	282	214	117	115	43	40 1,518
Pingelly	(51)	33	40	69	99	238	320	331	259	174	107	49	47 1,766
Corrigin	(32)	47	53	95	85	204	244	264	212	129	106	64	66 1,569
Kulin	(22)	57	63	106	86	233	227	237	174	121	112	62	68 1,546
Wickepin	(30)	41	51	84	103	229	284	295	222	145	103	51	48 1,656
Dudinin	(26)	60	45	90	80	188	265	275	203	135	123	55	37 1,556
Wagin	(51)	36	53	92	125	221	300	303	240	181	126	47	41 1,765
Dumbleyung	(32)	53	55	94	122	206	237	260	215	144	131	61	60 1,638
Kirkerin	(29)	67	70	108	105	205	245	253	220	158	131	79	66 1,707
Lake Grace	(27)	69	52	122	97	195	211	210	178	122	112	56	52 1,476
Katanning	(50)	44	52	103	118	240	297	306	246	189	154	64	62 1,873
Broome Hill	(51)	44	57	102	118	221	284	281	233	198	154	70	52 1,814
Nyabing	(29)	56	57	96	108	222	246	262	217	152	130	73	59 1,678
Pingrup	(14)	83	30	158	81	204	203	234	199	140	139	77	34 1,582
Tambellup	(31)	72	63	110	126	242	263	267	221	182	157	78	66 1,847
Gnowangerup	(29)	68	64	106	137	207	229	222	182	156	142	71	64 1,648
Borden	(17)	68	35	115	86	156	182	190	135	127	130	69	73 1,366
Cranbrook	(49)	57	64	106	134	238	289	310	256	210	179	92	63 1,998
Hopetoun	(40)	68	62	144	160	238	257	255	227	193	169	103	92 1,968
Esperance	(58)	70	69	115	175	326	407	401	381	271	214	104	86 2,619

(c) *Savannah Woodland Zone.*

Northampton	....	....	(60)	23	42	55	79	261	453	415	324	184	97	35	22 1,990
Chapman	....	....	(36)	28	39	70	70	233	422	388	270	152	91	37	27 1,827
Geraldton	....	....	(64)	22	29	57	92	272	477	379	279	128	70	26	15 1,846
Greenough	....	....	(60)	16	31	56	91	290	498	391	300	157	80	27	15 1,479
Dongarra	....	....	(58)	16	36	58	84	286	463	373	273	152	77	28	16 1,395
Dandarragan	....	....	(44)	30	41	82	87	283	422	392	336	219	140	54	48 2,134
Moora	....	....	(44)	43	44	78	81	239	373	356	265	169	107	41	36 1,832
Barberton	....	....	(30)	48	48	77	87	233	355	344	264	158	99	50	40 1,803
New Norcia	....	....	(59)	30	41	82	87	283	422	392	336	219	140	54	48 2,134
Toodyay	....	....	(62)	31	38	80	95	284	402	429	349	202	141	49	38 2,138
York	....	....	(65)	33	46	73	86	239	331	337	280	154	104	45	41 1,769
Brookton	....	....	(33)	43	43	71	94	249	344	355	267	162	118	48	43 1,837
Wandering	....	....	(53)	35	42	93	128	330	461	475	391	283	194	68	60 2,560
Narrogin	....	....	(50)	38	56	88	112	262	344	371	292	209	141	55	47 2,015
Williams	....	....	(57)	29	43	75	122	277	384	397	329	227	143	65	48 1,387
Arthur	....	....	(51)	32	51	90	116	248	343	344	282	201	143	51	42 1,943
Darkan	....	....	(40)	32	38	71	128	301	394	442	343	241	170	58	37 2,255
Kojonup	....	....	(57)	48	59	95	132	277	358	358	307	236	185	84	61 2,200
Kendenup	....	....	(41)	67	59	123	173	303	330	381	321	282	246	108	83 2,476
Mount Barker	....	....	(55)	90	89	145	208	339	386	417	370	334	290	143	106 2,917

(d) *Forest and Coastal Districts.*

Gingin	....	....	(53)	31	42	76	121	433	615	633	500	304	221	57	45 3,078
Chidlow	....	....	(35)	46	64	85	156	495	735	779	636	400	258	89	53 3,796
Mundaring	....	....	(36)	36	67	101	204	574	818	895	719	473	307	93	65 4,352
Kalamunda	....	....	(33)	47	54	95	209	603	827	838	690	450	302	95	77 4,287
Guildford	....	....	(62)	34	40	67	165	485	679	677	559	346	225	69	47 3,393
Perth (Observatory)	....	....	(66)	33	40	81	171	505	709	672	571	336	219	76	54 3,467
Fremantle	....	....	(67)	29	41	69	158	445	636	619	473	277	173	62	45 3,027
Rottnest	....	....	(60)	24	39	54	141	439	641	599	443	255	151	57	38 2,881
Armadale	....	....	(41)	29	35	74	147	539	738	752	586	380	234	66	44 3,624
Rockingham	....	....	(44)	34	29	69	153	506	697	685	499	322	194	65	38 3,291
Jarrahdale	....	....	(59)	52	53	102	222	645	896	920	781	540	360	114	72 4,757
Mandurah	....	....	(52)	24	36	79	164	524	762	696	536	371	224	69	44 3,529
Pinjarra	....	....	(63)	34	42	82	186	539	761	731	616	386	253	90	58 3,778
Dwellingup	....	....	(15)	47	62	105	300	720	1,024	1,082	799	586	324	128	47 5,180
Marradong	....	....	(44)	36	44	69	142	409	549	590	457	323	203	70	47 2,939
Brunswick	....	....	(33)	46	64	85	181	581	810	802	625	440	290	110	50 4,084
Bunbury	....	....	(65)	40	50	93	170	512	706	673	514	348	232	94	54 3,486
Collie	....	....	(42)	57	58	96	192	522	701	755	584	460	308	114	62 3,909
Cape Naturaliste	....	....	(38)	41	60	93	149	479	682	673	446	301	217	83	48 3,272
Busselton	....	....	(61)	42	45	85	145	470	674	649	459	301	226	85	48 3,229
Donnybrook	....	....	(41)	45	63	111	176	569	768	776	608	463	298	116	61 4,054
Greenbushes	....	....	(49)	59	70	112	195	519	681	675	588	441	319	119	77 3,855
Cape Leeuwin	....	....	(45)	64	77	116	218	582	715	729	541	341	283	121	79 3,866
Manjimup	....	....	(26)	82	83	119	221	588	711	710	633	479	347	164	88 4,225
Pemberton	....	....	(6)	160	57	177	294	699	787	810	888	493	422	219	105 5,111
Bridgetown	....	....	(54)	58	59	107	170	458	591	581	514	384	291	110	74 3,397
Boyup Brook	....	....	(28)	50	58	87	148	366	484	491	407	283	212	88	34 2,708
Denmark	....	....	(40)	126	135	217	323	570	673	728	646	504	429	181	140 4,672
Albany	....	....	(65)	101	88	159	275	502	543	559	530	408	324	146	115 3,750
Eclipse Island	....	....	(52)	87	80	144	239	437	474	527	469	351	292	125	107 3,332

TABLE II.—ANNUAL AND SEASONAL RAINFALL, AND ANNUAL RAINFALL VARIATION.

The rainfall is given in points (100 points to an inch) and mm. The wet season indicates the four consecutive wettest months, and the dry season the four consecutive driest months. The annual rainfall variation per cent. departure from the mean is given within close limits, (after *Gentilli*). The column marked “%” indicates the proportion of the rainfall for the four wettest months as a fraction of the annual rainfall.

I.—NORTHERN PROVINCE.

—	Annual.	Wet Season.	Per cent.	Dry Season.	Ann. var.
Port George IV.	5,039 1,280	Dec.-Mar. 4,391 1,115	87	July-Oct. 79 20	15-20
Mount Barnett	3,457 879	“ 2,761 701	79	June-Sept. 57 14	15-20
Kimberley Downs	2,506 637	“ 2,124 540	85	July-Oct. 40 10	20-25
Beagle Bay	2,778 706	“ 2,243 570	81	“ 83 21	25-30
Turkey Creek	2,714 690	“ 2,242 570	82	June-Sept. 81 20	20-25
Wyndham*	2,510 637	“ 2,229 566	85	“ 43 11	15-20
Berby*	2,530 643	“ 2,141 544	85	July-Oct. 43 11	25-30
Broome*	2,301 584	“ 1,934 491	87	“ 39 10	30-35
Fitzroy Crossing	2,110 536	“ 1,827 464	87	“ 62 16	20-25
Hall's Creek*	1,961 499	“ 1,591 404	81	June-Sept. 75 19	25-30
La Grange	1,870 475	“ 1,517 385	92	July-Oct. 47 12	30-35
Anna Plains	1,447 368	“ 1,096 264	75	“ 45 11	30-35
Wollal	1,206 306	“ 978 242	81	Aug.-Nov. 26 7	...
Marble Bar*	1,315 334	“ 918 233	69	“ 78 20	30-35
Nullagine*	1,297 329	“ 909 231	70	July-Oct. 90 23	30-35
Hamersley	1,337 340	“ 983 250	74	“ 93 24	30-35
Condon	1,191 303	Jan.-Apl. 879 223	75	Aug.-Nov. 32 8	35-40
Port Hedland*	1,193 303	“ 827 210	69	Sept.-Dec. 37 12	35-40
Roebourne*	1,168 297	“ 831 219	71	Aug.-Nov. 42 11	40-45
Bamboo Creek	1,420 361	“ 947 241	67	“ 95 24	30-35
Tamb ey	1,562 397	“ 1,071 272	69	“ 89 23	25-35
Millstream	1,477 375	“ 1,001 254	67	“ 74 19	25-35
Whim Creek	1,467 373	“ 1,093 278	74	“ 66 17	40-50
Red Hill	1,356 344	“ 909 231	67	“ 65 17	45-50
Bonny Downs	1,131 287	Dec.-Mar. 772 196	68	July-Oct. 78 20	35-40

II.—EREMEAN PROVINCE.

(a) Northern Zone.

—	points. mm.	points. mm.	points. mm.	points. mm.	points. mm.
Mundiwindi*	1,021 259	Dec.-Mar. 632 161	62	July-Oct. 122 31	35-40
Ethel Creek	1,001 254	“ 644 163	64	“ 82 21	35-40
Roy Hill	1,001 254	“ 667 169	67	Aug.-Nov. 82 21	35-40
Three Rivers	872 221	“ 482 122	55	“ 82 21	35-40
Kathleen Valley	785 199	“ 394 101	50	“ 116 29	35-40
Mardie	870 220	Jan.-April 605 154	58	Sept.-Dec. 40 10	35-40
Winning Pool*	986 205	“ 512 130	51	“ 56 14	40-45
Flaming Head	1,215 309	“ 752 191	61	“ 10 2	30-35
Wandagee	901 228	“ 436 111	48	“ 61 15	40-45
Peak Hill	940 239	“ 498 126	53	Aug.-Nov. 106 27	35-40
Wiluna*	938 238	“ 514 131	55	“ 111 28	35-40
Meekatharra*	909 231	“ 465 118	51	Sept.-Dec. 122 31	35-40
Nannine	781 198	“ 384 98	49	“ 95 24	35-40
Mt. Sir Samuel	901 228	“ 427 108	47	Aug.-Nov. 139 35	35-40

(b) Central Zone.

—	points. mm.	points. mm.	points. mm.	points. mm.	points. mm.
Onslow*	910 230	Mar.-June 571 145	63	Sept.-Dec. 25 6	55-60
Cue*	851 216	“ 389 99	46	“ 131 33	35-40
Mount Magnet	804 230	“ 391 99	43	“ 141 36	30-35
Sandstone	879 223	“ 384 98	44	“ 110 27	25-30
Lawlers	817 208	“ 390 99	47	Aug.-Nov. 140 36	25-30
Youanmi	886 225	“ 400 102	35	Sept.-Dec. 180 46	25-30
Doyle's Well	874 222	“ 432 110	50	Aug.-Nov. 148 38	25-30
Leonora	832 211	“ 387 98	47	Sept.-Dec. 159 40	30-35
Malcolm	876 222	“ 408 104	46	“ 168 43	30-35
Murrin Murrin	876 222	“ 408 104	46	“ 188 48	30-35
Laverton	899 228	“ 413 105	46	Aug.-Nov. 186 47	30-35
Morgans	817 208	“ 396 101	49	July-Oct. 176 45	30-35
Yundramindra	860 218	“ 393 100	45	Aug.-Nov. 168 43	30-35
Kookynie	958 243	“ 425 108	44	“ 218 55	30-35
Menzies*	930 236	“ 410 102	43	Sept.-Dec. 190 48	25-30
Davyhurst	1,012 257	“ 436 111	43	“ 232 59	20-25
Bulong	922 234	“ 384 98	42	Oct.-Jan. 244 62	20-25
Zanthus	973 247	“ 434 110	45	Sept.-Dec. 259 66	25-30
Kanowna	946 240	“ 402 102	43	“ 241 61	25-30
Kalgoolie*	951 242	“ 414 105	43	“ 237 60	20-25
Widgiemooltha	1,095 278	“ 463 117	54	Nov.-Feb. 293 74	20-25
Balladonia*	931 236	“ 361 92	39	“ 242 61	20-25
Rawlinna*	637 162	“ 262 66	41	“ 186 47	25-30
Loongana	615 156	“ 240 61	39	Sept.-Dec. 154 39	30-35
Eucla	995 253	April-July 430 109	44	Nov.-Feb. 237 60	20-25

II.—EREMEAN PROVINCE—continued.

(c) *Western Zone.*

—	Annual.	Wet Season.			Per. cent.	Dry Season.			Ann. var.	
Gascoyne Junction	855	217	May-Aug.	411	104	48	Sept.-Dec.	51	13	35-40
Hamelin Pool*	791	201	"	548	139	69	Oct.-Jan.	94	24	30-35
Carnarvon*	898	228	"	636	162	71	"	95	24	35-40
Wooramel	789	200	"	521	132	66	Sept.-Dec.	69	17	35-40
Shark Bay	898	228	"	636	162	71	Oct.-Jan.	65	16	35-40
Boolardy	790	201	"	422	107	54	Sept.-Dec.	73	18	35-40
Murgoo	816	207	"	451	114	63	"	88	22	35-40
Yuin	800	203	"	461	117	58	"	99	25	25-30
Yalgoo	999	254	"	538	136	53	"	147	37	25-30
Wubin	1,185	301	"	763	194	64	Oct.-Jan.	147	37	20-25
Goodlands	1,085	276	"	624	158	57	Nov.-Feb.	170	43	25-30
Kulja*	1,109	282	"	684	174	62	Dec.-Mar.	162	41	25-30
Mollerin	1,095	278	"	655	166	59	Nov.-Feb.	170	43	25-30
Wialki	1,109	282	"	623	158	57	"	200	51	25-30
Bonnie Rock	933	237	"	511	130	54	Jan.-April	177	45	
Gabbin	1,307	332	"	730	185	59	Nov.-Feb.	190	48	25-30
Koorda	1,125	286	"	627	159	55	"	190	48	20-25
Mandiga	1,251	318	"	670	170	56	"	220	56	25-30
Beneubbin	1,214	308	"	651	165	53	Oct.-Jan.	220	56	25-30
Mukinbudin	1,024	260	"	545	138	53	Dec.-Mar.	176	45	25-30
Kununoppin	1,173	298	"	632	160	54	Nov.-Feb.	188	48	20-25
Nungarin	1,209	307	"	675	171	56	"	197	50	20-25
Burracoppin	1,223	311	"	686	174	56	"	176	45	20-25
Walgoon	1,196	304	"	619	157	52	Sept.-Dec.	238	60	20-25
Newcarrie	1,217	309	"	653	166	53	Nov.-Feb.	199	51	20-25
Westonia	1,285	327	"	704	179	55	"	203	51	20-25
Bullfinch	1,141	292	"	561	142	49	"	243	62	20-25
Southern Cross*	1,052	267	"	530	134	50	"	207	53	20-25
Marvel Loch	1,255	319	"	623	158	51	"	226	57	20-25
Lake King	1,347	342	"	654	166	48	"	247	63	15-20
Lake Varley	1,358	345	"	664	168	49	"	231	59	15-20
Salmon Gums	1,316	334	"	627	159	49	"	327	83	15-20
Coogardie	1,009	256	"	423	107	42	"	267	68	15-20
Norseman	1,067	271	"	438	111	41	"	280	71	20-25
Grasspatch	1,511	384	"	682	173	45	"	368	93	20-25
Eyre	1,168	297	"	567	144	41	"	255	65	20-25

III.—SOUTH-WESTERN PROVINCE.

(a) *Eastern Zone.*

—	points. mm.	points. mm.	points. mm.	points. mm.	Sept.-Dec.	Oct.-Jan.	Nov.-Feb.	points. mm.	
Latham	1,181	300	May-Aug.	667	169	57	"	142	36
Wubin	1,185	301	"	763	194	65	"	147	37
Gabbin	1,307	332	"	730	185	59	"	190	48
Cadoux	1,381	351	"	833	212	60	"	206	52
Wyalkatchem	1,345	342	"	725	184	54	"	208	53
Korrellocking	1,355	344	"	781	198	56	"	193	49
Trayning	1,266	321	"	698	177	55	"	202	51
Kellerberrin*	1,329	338	"	779	198	58	"	185	47
Doodlakine	1,235	314	"	678	172	55	"	204	52
Merredin	1,292	328	"	726	184	59	"	187	47
Bruce Rock	1,373	349	"	766	195	56	"	220	56
Narembeen	1,166	296	"	710	179	63	"	150	38
Kondinin	1,340	340	"	759	193	56	"	192	49
Hyden	1,320	335	"	714	181	46	"	247	63
Newdegate	1,398	355	"	733	186	52	"	243	62
Jarramongup	1,531	389	"	736	187	48	"	254	65
Buntine	1,407	357	"	770	196	49	Oct.-Jan.	192	49
Ongeup	1,564	397	"	770	196	49	Nov.-Feb.	267	68

(b) *Central Zone.*

—	points. mm.	points. mm.	points. mm.	points. mm.	Nov.-Feb.	Oct.-Jan.	Nov.-Feb.	points. mm.	
Ajana	1,336	339	May-Aug.	933	237	70	"	120	30
Yuna	1,421	361	"	946	240	67	"	160	41
Mullewa	1,308	332	"	863	219	66	"	155	39
Canna	1,485	377	"	894	227	60	"	207	52
Mingenew*	1,642	417	"	1,141	290	69	Nov.-Feb.	137	35
Morawa*	1,392	353	"	806	205	58	Oct.-Jan.	221	56
Perenjori	1,343	341	"	809	205	60	"	172	44
Three Springs	1,567	398	"	1,025	260	66	Nov.-Feb.	196	50
Carnamah*	1,580	401	"	1,035	263	65	"	181	46
Coorow	1,567	398	"	1,010	255	55	"	190	48
Watheroo	1,636	415	"	1,071	272	65	"	160	41
Dalwallinu	1,421	361	"	852	216	60	Oct.-Jan.	219	56
Ballidu	1,322	336	"	804	204	61	Nov.-Feb.	180	46
Miling	1,586	403	"	996	253	63	"	214	54
Kondut	1,384	351	"	857	218	62	"	183	46
Walebing	2,013	511	"	1,324	336	65	"	188	48
Wongan Hills	1,476	375	"	948	241	64	"	180	46
Cadoux	1,381	352	"	833	207	63	"	206	52
Calingiri	1,731	440	"	1,169	297	67	"	164	42

III.—NORTH-WESTERN PROVINCE—*continued.*(b) *Central Zone—continued.*

—	Annual.	Wet Season.	Per cent.	Dry Season.	Ann. var.		
Goomalling	1,418	360	May-Aug.	points. 893 mm. 227	63	Nov.-Feb. points. 178 mm. 45	20-25
Dowerin	1,479	376	”	919 233	60	” 204 52	20-25
Northam	1,711	435	”	1,147 291	67	” 151 38	15-20
Meckering	1,526	388	”	997 253	65	” 150 38	20-25
Cunderdin	1,458	370	”	906 230	62	” 179 45	20-25
Tammin	1,378	350	”	806 205	58	” 184 47	20-25
Beverley	1,688	429	”	1,127 286	67	” 148 38	15-20
Quairading	1,518	385	”	930 236	62	” 185 47	15-20
Pingelly	1,766	448	”	1,148 292	65	” 169 43	15-20
Corrigin	1,569	398	”	924 235	59	” 230 58	15-20
Kulin	1,546	393	”	871 221	56	” 250 63	15-20
Wickepin	1,656	421	”	1,020 262	62	” 191 49	15-20
Dudinin	1,556	395	”	931 236	59	” 197 50	10-15
Wagin	1,765	448	”	1,064 270	60	” 177 45	15-20
Dumbleyung	1,638	416	”	918 233	56	” 229 58	15-20
Kukerin	1,707	433	”	933 237	54	” 282 72	15-20
Lake Grace	1,476	375	”	794 202	54	” 229 58	15-20
Katanning*	1,873	476	”	1,089 277	58	” 222 56	15-20
Broome Hill	1,814	461	”	1,019 259	56	” 223 56	15-20
Nyabing	1,678	426	”	947 240	56	” 245 62	10-15
Pingrup	1,582	402	”	840 213	52	” 224 57	10-15
Tambellup	1,847	469	”	993 252	54	” 279 71	10-15
Gnowangerup	1,648	418	”	840 213	57	” 267 68	15-20
Borden	1,366	337	”	663 168	57	” 245 62	15-20
Cranbrook	1,998	507	”	1,093 277	55	” 276 70	10-15
Hopetoun	1,968	500	”	977 248	50	” 325 82	10-15
Esperance*	2,619	665	”	1,515 385	58	” 329 83	10-15
Northampton	1,990	505	”	1,453 369	73	” 122 31	15-20
Chapman (R.S.)	1,827	464	”	1,313 335	72	” 131 33	15-20
Geraldton*	1,846	469	”	1,407 357	76	” 92 23	15-20
Greenough	1,952	496	”	1,479 376	75	” 89 22	20-25
Dongarra	1,862	473	”	1,395 354	75	” 96 24	20-25
Dandaragan	2,134	542	”	1,433 364	67	” 173 44	15-20
Moora	1,832	465	”	1,233 313	67	” 164 41	15-20
Barberton	1,803	458	”	1,196 304	66	” 186 47	15-20
New Norcia	2,134	542	”	1,433 364	56	” 173 44	15-20
Toodyay	2,138	543	”	1,464 372	68	” 156 40	15-20
York	1,769	449	”	1,187 301	67	” 165 42	15-20
Brookton	1,837	467	”	1,215 309	66	” 177 45	15-20
Wandering	2,560	650	”	1,657 421	64	” 205 52	15-20
Narrogin	2,015	512	”	1,269 322	63	” 196 50	10-15
Williams	2,139	543	”	1,387 254	65	” 185 47	15-20
Arthur	1,943	493	”	1,217 309	62	” 176 45	15-20
Darkan	2,255	573	”	1,480 276	65	” 165 42	15-20
Kojonup	2,200	559	”	1,300 330	59	” 252 64	15-20
Kendenup	2,476	629	”	1,335 339	54	” 317 81	10-15
Mount Barker	2,917	741	”	1,512 384	52	” 428 109	10-15

(c) *Western Zone.*

—	points. mm.	May-Aug.	points. mm.	Nov.-Feb.	points. mm.		
Gingin	3,078	782	May-Aug.	2,181 554	71	Nov.-Feb. 175 44	15-20
Chidlow	3,796	964	”	2,645 672	70	” 252 64	15-20
Mundaring	4,352	1,105	”	3,006 763	69	” 261 66	15-20
Kalamunda	4,287	1,089	”	2,958 751	69	” 273 69	15-20
Guildford	3,393	862	”	2,400 610	71	” 190 48	15-20
Perth Observatory	3,467	881	”	2,457 624	71	” 203 51	15-20
Fremantle	3,027	769	”	2,173 552	72	” 177 45	15-20
Rottnest	2,881	732	”	2,122 539	75	” 158 40	15-20
Armadale	3,624	932	”	2,615 664	71	” 174 44	15-20
Rockingham	3,291	836	”	2,387 606	73	” 166 42	15-20
Jarrahdale	4,757	1,208	”	3,242 823	68	Dec.-Mar. 369 94	10-15
Mandurah	3,529	896	”	2,518 639	69	Nov.-Feb. 173 44	10-15
Pinjarra	3,778	959	”	2,647 672	71	Dec.-Mar. 216 55	10-15
Dwellingup	5,180	1,316	”	3,625 921	71	” 261 66	10-15
Marradong	2,939	747	”	2,005 509	68	” 196 49	10-15
Brunswick	4,084	1,037	”	2,818 716	69	” 254 62	10-15
Bunbury	3,486	885	”	2,405 611	70	” 237 60	10-15
Collie	3,909	993	”	2,562 651	65	” 273 69	10-15
Cape Naturaliste	3,272	831	”	2,280 579	70	” 242 61	10-15
Busseton	3,229	820	”	2,252 572	69	” 220 56	10-15
Donnybrook	4,054	1,030	”	2,721 691	67	” 280 71	10-15
Greenbushes	3,855	979	”	2,463 626	64	” 318 81	10-15
Cape Leeuwin	3,866	982	”	2,567 652	64	” 336 85	10-15
Manjimup	4,225	1,073	”	2,642 671	63	” 372 95	10-15
Pemberton	5,111	1,298	”	3,184 809	45	” 499 127	10-15
Bridgetown	3,397	863	”	2,144 545	64	” 298 76	10-15
Boyup Brook	2,708	688	”	1,748 444	64	” 229 58	10-15
Denmark	4,672	1,187	”	2,617 665	47	Nov.-Feb. 582 148	10-15
Albany	3,750	952	”	2,134 542	57	” 450 114	10-15
Eclipse Island	3,332	846	”	1,907 484	58	” 399 101	10-15

TABLE III.—RELATIVE HUMIDITY.

(a) Readings taken at 9.0 a.m.

(b) Readings taken at 3.0 p.m.

The higher readings are in heavy type.

(Those stations with less than three years records are marked †. The figures for 1941 alone are given.)

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Wyndham	.... (a) 54	69	56	46	41	42	40	43	44	51	56	55	52
	.... (b) 54	54	49	38	37	37	35	39	43	47	50	52	45
Hall's Creek	.... (a) 51	52	46	35	37	40	37	33	29	32	34	45	42
	.... (b) 36	36	33	27	29	32	30	26	24	26	22	25	28
Derby	.... (a) 70	79	66	52	47	47	47	46	47	51	56	63	55
	.... (b) 58	59	53	42	40	40	40	38	39	43	50	54	46
Broome	.... (a) 72	73	69	54	52	54	52	53	52	57	60	66	59
	.... (b) 67	67	59	45	44	46	43	42	44	52	57	62	52
Anua Plains	.... (a) 69	69	61	43	42	48	49	42	30	45	49	54	51
Port Hedland	.... (a) 62	62	56	46	47	50	47	47	44	46	48	56	51
	.... (b) 63	63	56	49	49	47	47	49	49	53	55	61	53
Marble Bar	.... (a) 44	46	43	39	46	48	45	39	32	30	29	36	40
	.... (b) 21	28	27	26	31	33	30	26	22	20	19	23	26
Roebourne	.... (a) 49	51	52	43	46	50	45	45	37	37	36	42	44
	.... (b) 41	42	43	36	38	40	36	36	29	33	33	37	37
Mundiwindi	.... (a) 29	30	34	33	42	49	44	38	26	22	20	25	44
	.... (b) 17	18	20	19	25	28	23	19	13	12	11	15	18
Onslow	.... (a) 52	54	54	52	56	60	57	52	46	44	44	47	52
	.... (b) 52	54	53	50	52	54	51	47	45	44	48	50	50
Winning Pool	(a) 45	49	49	45	50	54	48	43	41	38	37	40	45
	(b) 24	26	28	27	33	37	32	39	25	23	20	22	28
Carnarvon	.... (a) 57	60	58	57	60	66	66	62	57	55	56	57	59
	.... (b) 61	62	61	59	60	59	57	59	59	59	60	62	60
Gascoyne Junct.†	(a) 34	48	36	51	60	61	59	45	46	43	40	39	55
	(b) 19	21	23	32	45	49	40	29	29	30	20	20	31
Hamelin Pool	.... (a) 43	46	48	52	62	69	60	64	55	49	44	43	54
	.... (b) 36	38	40	45	54	60	59	54	47	43	39	38	46
Meekatharra	.... (a) 31	29	58	41	50	60	61	53	40	33	31	27	41
	.... (b) 18	19	33	27	34	41	43	35	23	20	19	17	27
Wiluna	.... (a) 35	37	42	46	53	59	57	51	42	38	34	33	44
	.... (b) 25	27	30	33	39	42	39	35	31	28	25	24	31
Laverton	.... (a) 36	37	44	47	54	61	60	52	41	37	35	34	45
	.... (b) 24	25	30	33	40	46	43	37	28	26	24	24	32
Cue	.... (a) 36	39	43	49	59	68	67	60	49	43	37	35	49
	.... (b) 25	26	29	34	42	49	48	42	33	29	25	24	34
Menzies	.... (a) 37	39	45	52	59	66	65	57	45	41	36	36	48
	.... (b) 23	24	29	35	42	48	45	39	30	26	23	22	32
Yalgoo	.... (a) 40	44	51	56	66	76	77	71	58	49	42	39	56
	.... (b) 25	28	33	37	44	54	54	47	38	31	26	24	37
Rawlinna	.... (a) 49	52	59	59	64	70	70	63	51	48	47	48	57
	.... (b) 23	26	35	31	35	44	40	35	26	21	22	21	30
Eucla	.... (a) 59	61	60	61	65	71	70	63	56	53	55	56	61
	.... (b) 62	63	62	58	56	57	56	54	54	57	60	61	58
Balladonia	.... (a) 54	58	64	69	74	77	77	70	60	55	53	53	64
	.... (b) 34	36	42	46	52	58	55	48	40	37	35	35	43
Kalgoorlie	.... (a) 46	49	55	59	66	74	74	66	53	48	44	43	56
	.... (b) 27	30	34	39	46	52	50	44	34	31	28	27	37
Southern Cross	.... (a) 46	51	56	61	73	81	83	76	63	55	49	46	62
	.... (b) 29	32	40	42	51	60	60	54	43	38	34	30	42
Kulja†	.... (a) 37	46	47	65	60	86	87	71	61	47	42	41	57
	.... (b) 19	24	25	40	45	64	52	47	44	26	23	22	36
Salmon Gums†	.... (a) ....	....	65	74	81	79	80	67	63	56	47	51	65

TABLE III.—RELATIVE HUMIDITY—*continued.*

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Kellerberrin	.... (a) 51	54	62	65	78	83	86	80	70	58	49	48	65
	(b) 30	32	38	42	54	61	62	57	47	38	32	34	44
Northam	.... (a) 65	71	58	66	79	85	87	80	71	60	50	49	76
	(b) 36	42	31	45	57	65	65	59	53	45	35	33	47
Geraldton	.... (a) 54	56	57	58	85	70	70	68	63	58	55	55	61
	(b) 60	60	60	58	58	60	60	59	59	59	60	60	59
Watheroo	.... (a) 38	40	48	53	68	77	80	71	60	50	40	37	53
Perth Observatory	.... (a) 51	53	57	62	71	76	77	72	67	61	54	51	63
	(b) 44	42	45	49	58	63	63	61	58	55	49	47	53
Carnamah†	.... (a) 33	47	45	67	62	85	81	78	67	50	46	44	59
	(b) 16	20	21	39	45	66	59	53	45	33	31	24	38
Katanning	.... (a) 55	59	65	72	81	86	87	82	76	67	58	55	70
	(b) 35	37	43	50	62	69	69	65	58	52	40	37	51
Bunbury	.... (a) 50	61	64	72	77	80	80	77	73	68	63	61	70
	(b) 57	56	58	63	68	70	71	69	67	65	60	59	64
Esperance	.... (a) 62	63	66	70	75	78	78	74	69	65	62	61	69
	(b) 63	64	64	65	64	65	65	62	63	64	64	63	64
Collie†	.... (a)	69	79	89	88	88	92	88	80	62	57	51	75
Manjimup†	.... (a) 63	57	77	77	78	87	90	87	82	74	75	66	75
Cape Leeuwin†	.... (a) 89	88	88	73	76	86	83	80	85	80	89	89	84
	(b) 88	85	83	73	73	82	80	78	77	80	89	89	81
Albany	.... (a) 71	72	74	79	81	77	81	79	77	74	71	69	76
	(b) 65	66	67	68	69	70	70	68	69	68	67	65	68

TABLE IV.—SATURATION DEFICIT.

(Inches of mercury).

Taken from 9.0 a.m. and 3.0 p.m. wet and dry bulb readings.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Wyndham	.... (a) .417	.380	.446	.663	.629	.538	.525	.569	.656	.650	.608	.514	.550
	(b) .710	.700	.790	.960	.880	.750	.770	.760	.800	.810	.820	.760	.792
Derby	.... (a) .366	.355	.415	.566	.539	.448	.438	.500	.577	.622	.578	.488	.492
	(b) .590	.640	.700	.880	.790	.680	.680	.760	.870	.880	.750	.700	.786
Broome	.... (a) .336	.325	.370	.515	.440	.347	.346	.372	.462	.499	.499	.425	.437
	(b) .420	.420	.580	.800	.680	.570	.560	.630	.670	.580	.550	.520	.591
Hall's Creek	.... (a) .634	.598	.695	.716	.572	.428	.433	.580	.795	.928	.944	.707	.715
	(b) 1.050	1.050	1.050	1.800	.880	.710	.710	.890	1.140	1.300	1.330	1.150	1.015
Anna Plains	.... (a) .376	.365	.476	.598	.469	.335	.310	.418	.507	.611	.650	.619	.601
	(b) ....	....	....	....	....	....	....	....	....	....	....	....	....
Marble Bar	.... (a) .828	.765	.764	.702	.457	.353	.359	.451	.671	.865	1.085	.977	.690
	(b) 1.600	1.520	1.340	1.210	.870	.700	.690	.870	1.170	1.450	1.690	1.680	1.184
Port Hedland	.... (a) .497	.516	.574	.621	.465	.358	.349	.406	.536	.599	.687	.603	.518
	(b) .530	.530	.690	.690	.570	.510	.460	.480	.560	.550	.600	.570	.565
Roebourne	.... (a) .807	.758	.666	.707	.482	.361	.375	.430	.624	.741	.942	.894	.649
	(b) 1.070	1.070	.980	.960	.730	.580	.600	.680	.920	.980	1.180	1.160	.885
Mundiwindi	.... (a) .976	.892	.739	.574	.366	.254	.266	.332	.543	.708	.964	.995	.634
	(b) 1.480	1.450	1.230	.970	.680	.510	.540	.640	.960	1.150	1.460	1.560	1.005

TABLE IV.—SATURATION DEFICIT—*continued.*

Station.		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Onslow	(a)	.624	.576	.557	.516	.365	.273	.267	.341	.449	.555	.647	.666	.486
	(b)	.690	.730	.670	.630	.550	.420	.410	.500	.570	.660	.670	.700	.582
Wihma	(a)	.826	.769	.615	.428	.269	.179	.180	.235	.363	.501	.719	.823	.492
	(b)	1.300	1.270	1.040	790	.500	.380	.370	.460	.670	.870	1.110	1.310	.785
Meekatharra	(a)	.879	.863	.561	.450	.280	.170	.151	.206	.340	.495	.677	.846	.493
	(b)	1.410	1.480	1.080	.830	.570	.380	.340	.460	.700	.920	1.160	1.420	.839
Cue	(a)	.791	.716	.566	.390	.225	.134	.133	.184	.300	.413	.610	.757	.435
	(b)	1.370	1.300	1.040	.750	.500	.320	.310	.420	.610	.790	1.060	1.310	.755
Laverton	(a)	.711	.652	.496	.383	.258	.160	.163	.227	.357	.461	.621	.709	.434
	(b)	1.220	1.160	.920	.710	.440	.340	.330	.410	.640	.820	.990	1.200	.719
Menzies	(a)	.648	.571	.456	.322	.206	.135	.134	.185	.303	.390	.555	.637	.379
	(b)	1.170	1.110	.900	.600	.400	.300	.290	.390	.580	.740	1.010	1.150	.675
Rawlinna	(a)	.385	.365	.280	.238	.168	.113	.103	.142	.235	.297	.376	.366	.256
	(b)	.920	.940	.670	.620	.460	.340	.360	.410	.550	.740	.900	.990	.640
Carnarvon	(a)	.455	.427	.435	.397	.291	.199	.185	.152	.302	.359	.305	.422	.341
	(b)	.420	.430	.460	.430	.350	.320	.310	.280	.330	.350	.370	.390	.383
Yalgoo	(a)	.677	.576	.434	.312	.174	.099	.093	.124	.215	.338	.509	.643	.349
	(b)	1.270	1.210	.940	.700	.460	.290	.280	.350	.530	.690	1.010	1.220	.691
Kalgoorlie	(a)	.492	.434	.332	.249	.163	.099	.095	.138	.237	.337	.441	.504	.293
	(b)	1.080	1.020	.770	.570	.390	.270	.270	.340	.510	.670	.710	1.000	.608
Balladonia	(a)	.359	.320	.246	.184	.122	.085	.085	.123	.200	.269	.327	.351	.195
	(b)	.820	.780	.610	.480	.330	.240	.240	.310	.430	.540	.660	.750	...
Southern Cross	(a)	.511	.429	.332	.233	.123	.070	.060	.096	.181	.271	.404	.498	.267
	(b)	1.100	1.090	.780	.570	.330	.210	.210	.280	.400	.550	.800	1.020	.551
Watheroo	(a)	.588	.544	.419	.307	.159	.092	.080	.120	.199	.297	.458	.560	.319
	(b)	...	...	...	...	...	...	...	...	...	...	...	...	...
Kellerberrin	(a)	.428	.378	.275	.198	.099	.061	.051	.076	.136	.233	.369	.428	.228
	(b)	1.000	.910	.730	.540	.300	.210	.210	.240	.370	.500	.790	.940	.518
Northam	(a)	.459	.400	.314	.210	.098	.059	.049	.081	.138	.229	.370	.450	.238
	(b)	...	...	...	...	...	...	...	...	...	...	...	...	...
Esperance	(a)	.285	.272	.237	.183	.155	.095	.092	.114	.157	.199	.250	.281	.193
	(b)	.300	.300	.260	.240	.230	.190	.180	.210	.220	.230	.240	.290	.235
Geraldton	(a)	.452	.434	.398	.331	.227	.166	.152	.173	.225	.293	.364	.414	.302
	(b)	.390	.420	.420	.400	.330	.270	.260	.270	.280	.320	.340	.360	.330
Kataanning	(a)	.324	.283	.221	.149	.080	.052	.045	.065	.099	.159	.255	.315	.171
	(b)	.770	.720	.550	.390	.220	.150	.140	.170	.240	.330	.520	.690	.378
Perth Observatory	(a)	.417	.392	.323	.244	.144	.101	.096	.120	.167	.224	.320	.398	.246
	(b)	.590	.630	.520	.440	.270	.220	.180	.190	.250	.300	.400	.510	.366
Bunbury	(a)	.333	.310	.267	.170	.112	.088	.083	.098	.135	.181	.258	.309	.195
	(b)	.420	.420	.390	.290	.200	.160	.150	.150	.190	.230	.290	...	...
Dwellingup	(a)	.275	.261	.187	.120	.059	.036	.027	.062	.091	.138	.237	.280	.148
	(b)	...	...	...	...	...	...	...	...	...	...	...	...	...
Cape Leeuwin	(a)	.089	.093	.077	.099	.087	.070	.081	.089	.074	.085	.104	.090	.094
	(b)	.190	.190	.180	.140	.130	.090	.090	.120	.120	.170	.180	...	...
Albany	(a)	.191	.184	.153	.112	.099	.080	.072	.065	.098	.131	.174	.183	.128
	(b)	.250	.250	.210	.200	.190	.150	.150	.150	.190	.200	.240	...	...
Gascoyne Junction	...	.680	.568	.548	.441	.218	.159	.152	.232	.321	.351	.584	.691	.421
Kulja	...	.503	.428	.284	.197	.169	.070	.058	.125	.153	.280	.413	.501	.412
Carnamah	...	.567	.438	.254	.205	.160	.062	.073	.088	.154	.237	.419	.525	.270
Salmon Gums	...	.361	.135	.185	.151	.102	.067	.086	.134	.178	.246	.372	.367	.207
Collie	...	.267	.190	.096	.078	.044	.047	.024	.050	.074	.135	.231	.290	.128
Manjimup	...	.200	.175	.111	.101	.075	.049	.034	.054	.072	.124	.104	.151	.099

Based on Mean 9.0 a.m. readings for 1941–1942.

* Afternoon readings for Cape Leeuwin taken at 4.0 p.m.

TABLE V.—CLIMATIC ANALYSIS.

The first column of figures represents the average variation from the mean annual rainfall, expressed as a percentage departure from the mean.

Humidity (four columns)—

The morning and afternoon readings for the four consecutive wettest, and the four consecutive driest months respectively (*i.e.*, months of maximum and minimum precipitation).

Saturation deficit—

The first column gives the mean of the monthly readings for the year.

The second column gives the mean of the monthly mean readings for the four consecutive wettest months.

The third column gives the mean monthly readings for the four consecutive driest months (see Table II., in which these months are indicated).

MR = Meyer Ratio.

$\frac{SP}{SSD}$ = the mean precipitation for the four wettest months over the mean saturation deficit for the same period.

Temperature—

MAT is the normal mean annual temperature.

MST is the normal mean temperature for the four consecutive wettest months.

$\frac{SP}{MST}$ = Seasonal precipitation for the four consecutive wettest months.
Seasonal temperature

Station.	Annual Rainfall Variation.	Humidity.		Sat. Def. (9 a.m.).		M.R. (9·0 a.m.)	SP. SSD	Temp. ° C.		SP. MST
		Wet S.	Dry S.	Annual.	Wet.			MAT.	MST.	
Port George IV.	17	68	...	49	...	...	...	102	...	26·1
Wyndham	20	58	50	42	38	·550	·444	·549	45	30·0
Derby	30	70	64	53	45	·492	·406	·534	51	28·9
Broome	32	70	64	53	45	·437	·364	·420	52	31·1
Hall's Creek	29	48	32	35	28	·715	·658	·559	27	27·6
Anna Plains	32	63	...	43	...	·601	·459	·491	24	30·3
Marble Bar	34	45	26	32	22	·690	·833	·768	19	16·4
Port Hedland	40	56	58	48	54	·518	·552	·606	23	26·7
Roebourne	43	49	40	39	33	·649	·734	·684	18	31·1
Mundiwindi	34	29	17	32	17	·634	·900	·462	16	29·4
Onslow	60	55	52	55	52	·486	·428	·579	19	5·4
Wiluna	35	40	29	41	30	·492	·659	·454	19	5·9
Meekatharra	35	40	24	33	20	·493	·688	·589	18	17·8
Cue	36	55	38	41	28	·435	·330	·520	20	6·8
Laverton	31	51	37	47	34	·434	·326	·302	21	21·2
Menzies	30	55	38	39	25	·379	·280	·471	24	18·3
Rawlinna	29	63	36	39	23	·256	·200	·373	25	4·0
Carnarvon	37	63	59	56	60	·341	·225	·408	27	16·7
Yalgoo	28	72	50	47	30	·349	·122	·426	29	9·1
Kalgoorlie	22	64	43	47	30	·293	·211	·380	32	13·9
Southern Cross	24	78	56	48	31	·267	·087	·460	39	17·2
Watheroo	...	74	...	39	...	·319	·113	·537	51	10·0
Kellerberrin	20	82	59	50	32	·228	·069	·408	58	24·0
Northam	20	83	61	59	36	·238	·072	·371	72	12·2
Esperance	14	76	64	62	63	·193	·114	·272	136	23·9
Geraldton	19	68	59	55	60	·302	·179	·416	61	16·7
Katanning	17	84	66	57	37	·171	·060	·294	109	22·0
Perth Observatory	16	74	61	52	45	·246	·115	·383	141	15·6
Bunbury	16	78	69	59	57	·195	·095	·305	174	10·7
Dwellingup	...	87	66	62	40	·148	·046	·251	350	45·2
Cape Leeuwin	14	81	78	88	86	·085	·082	·087	411	14·4
Albany	14	79	69	71	66	·128	·077	·183	293	45·3

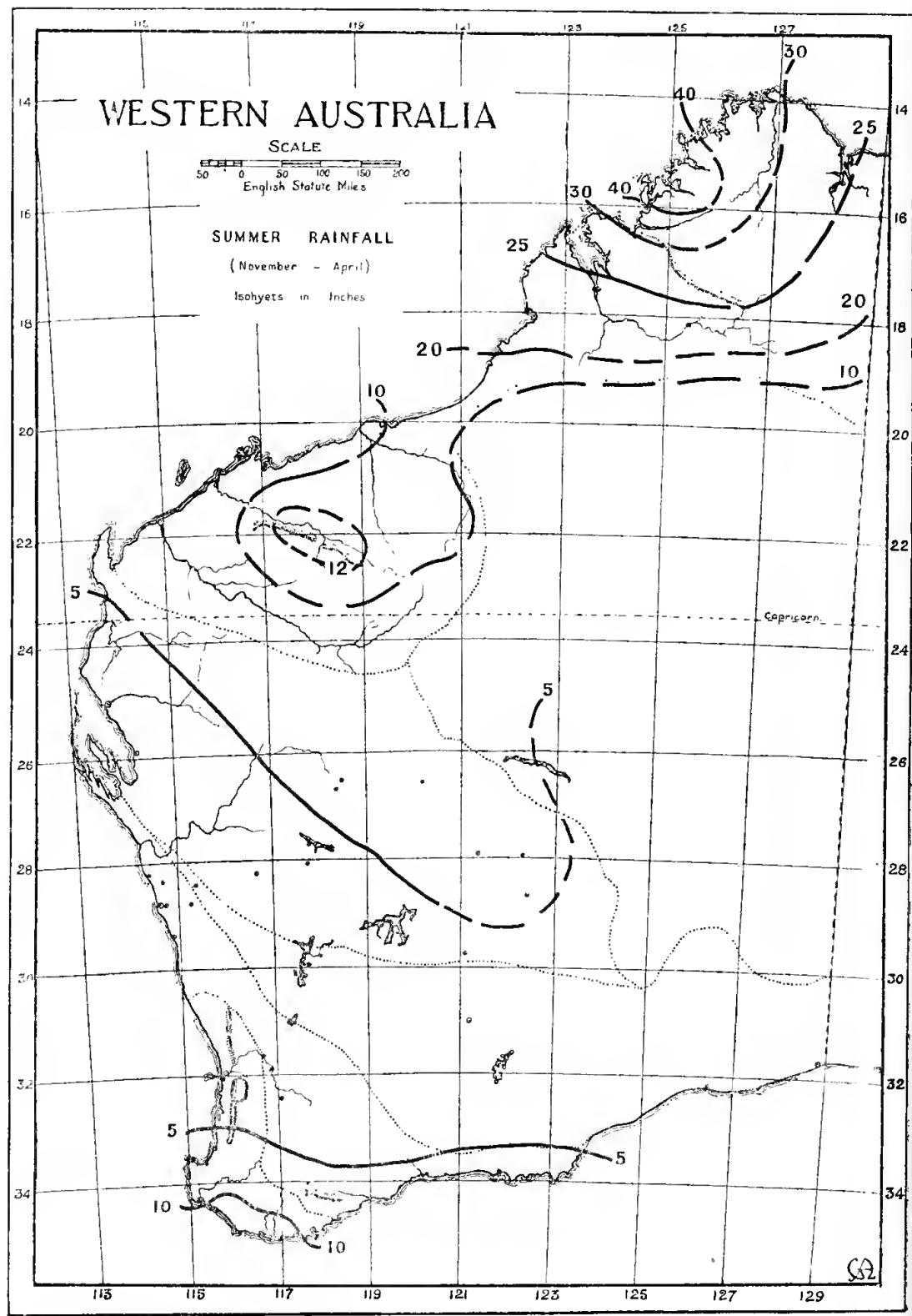


PLATE I.
 SUMMER RAINFALL (NOVEMBER-APRIL).
 Isohyets in inches.

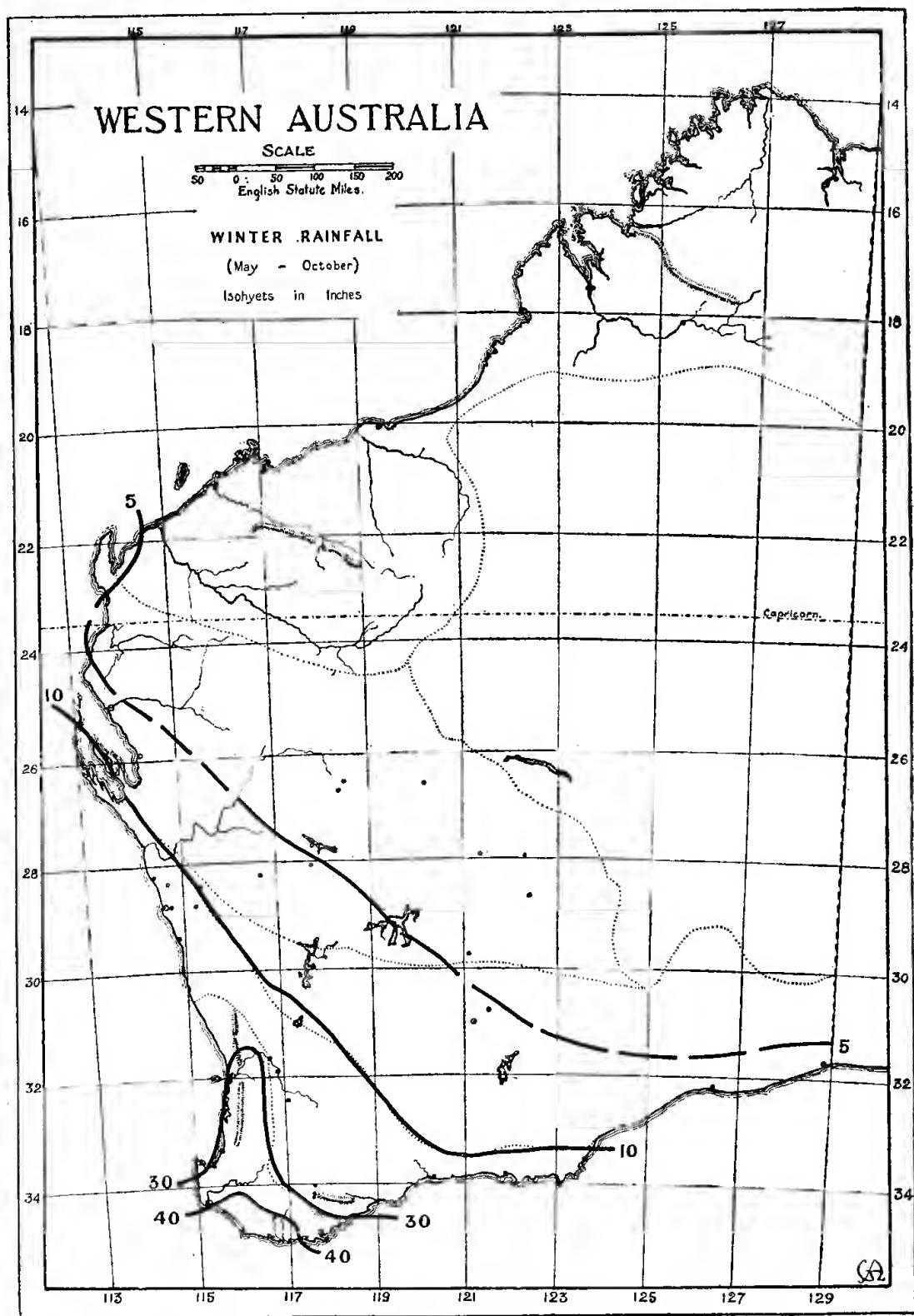


PLATE II.
WINTER RAINFALL (MAY-OCTOBER).
Isohyets in inches.

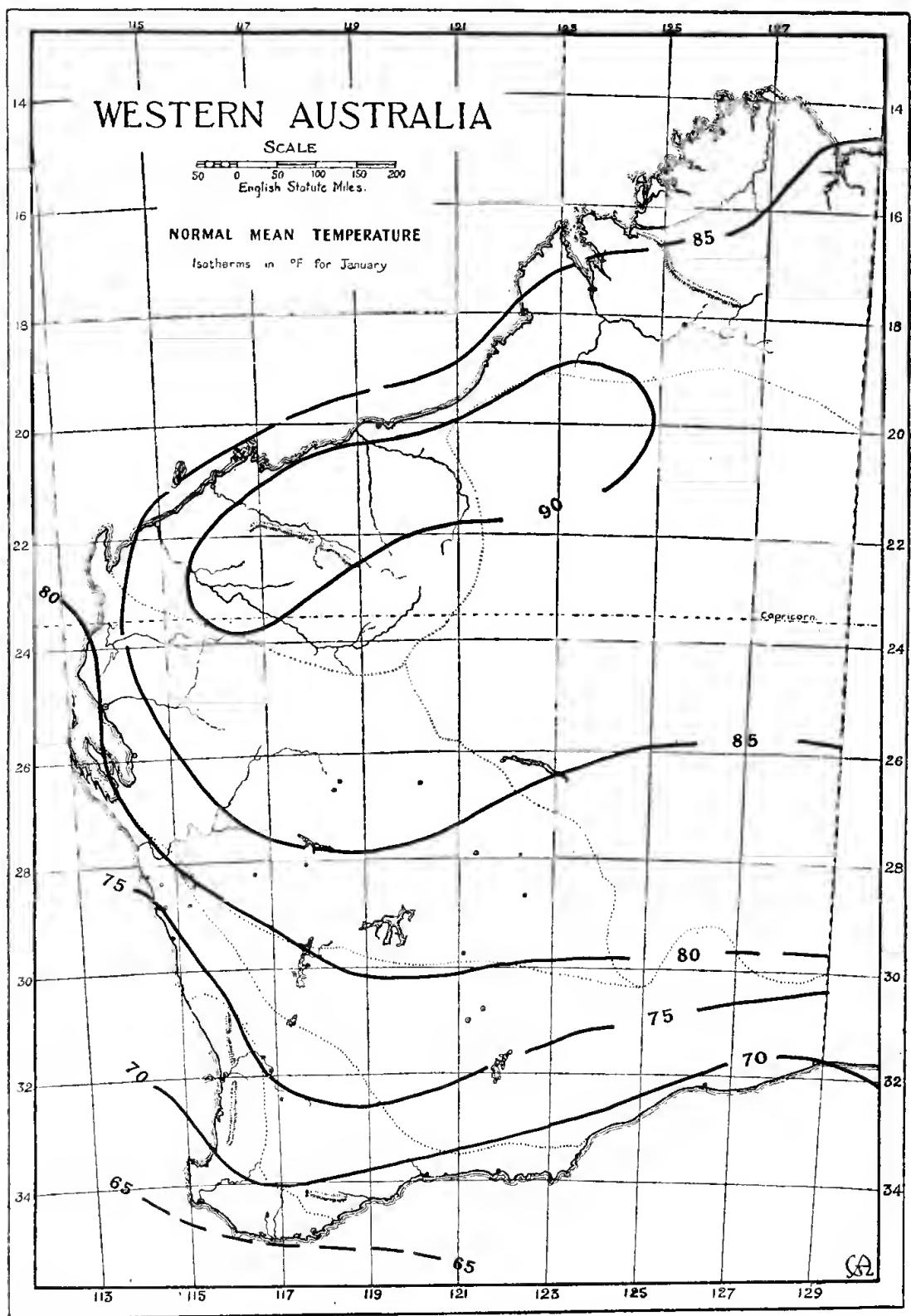


PLATE III.

NORMAL MEAN TEMPERATURE.

Isotherms in °F for January.

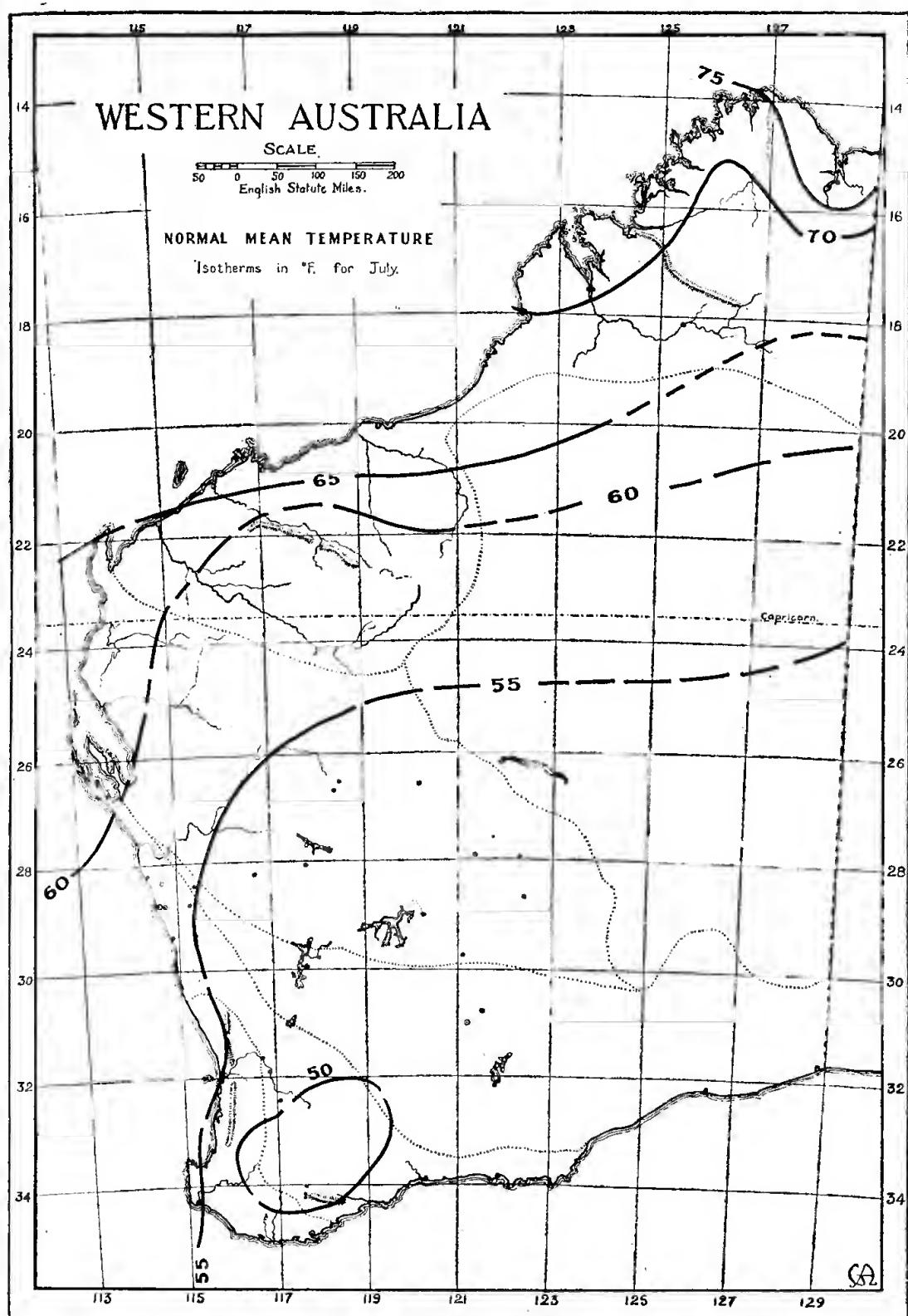


PLATE IV.

NORMAL MEAN TEMPERATURE.

Isotherms in °F. for July.

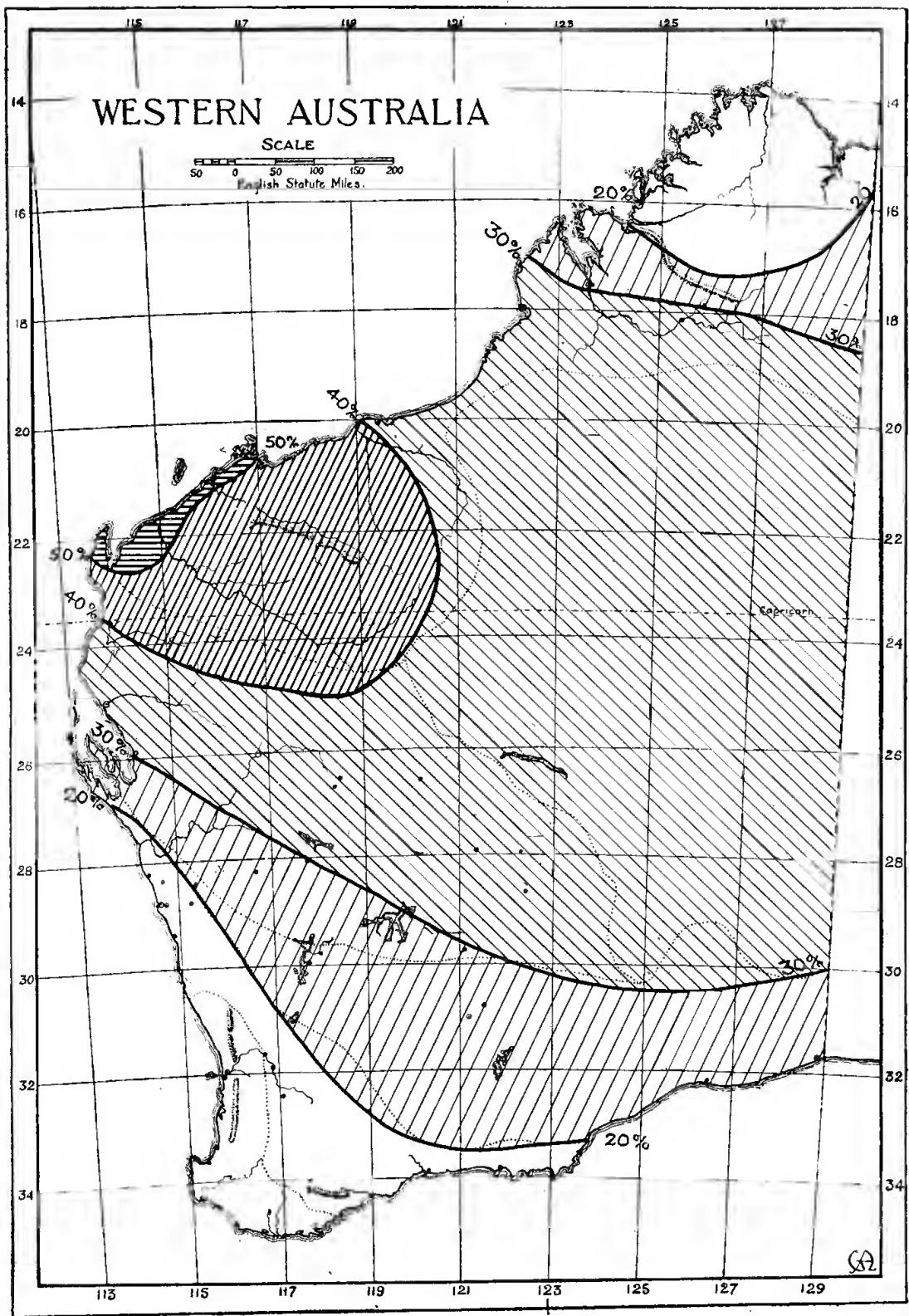


PLATE V.

RAINFALL VARIABILITY.

Variation in the annual rainfall expressed as a per cent. departure from the Mean.

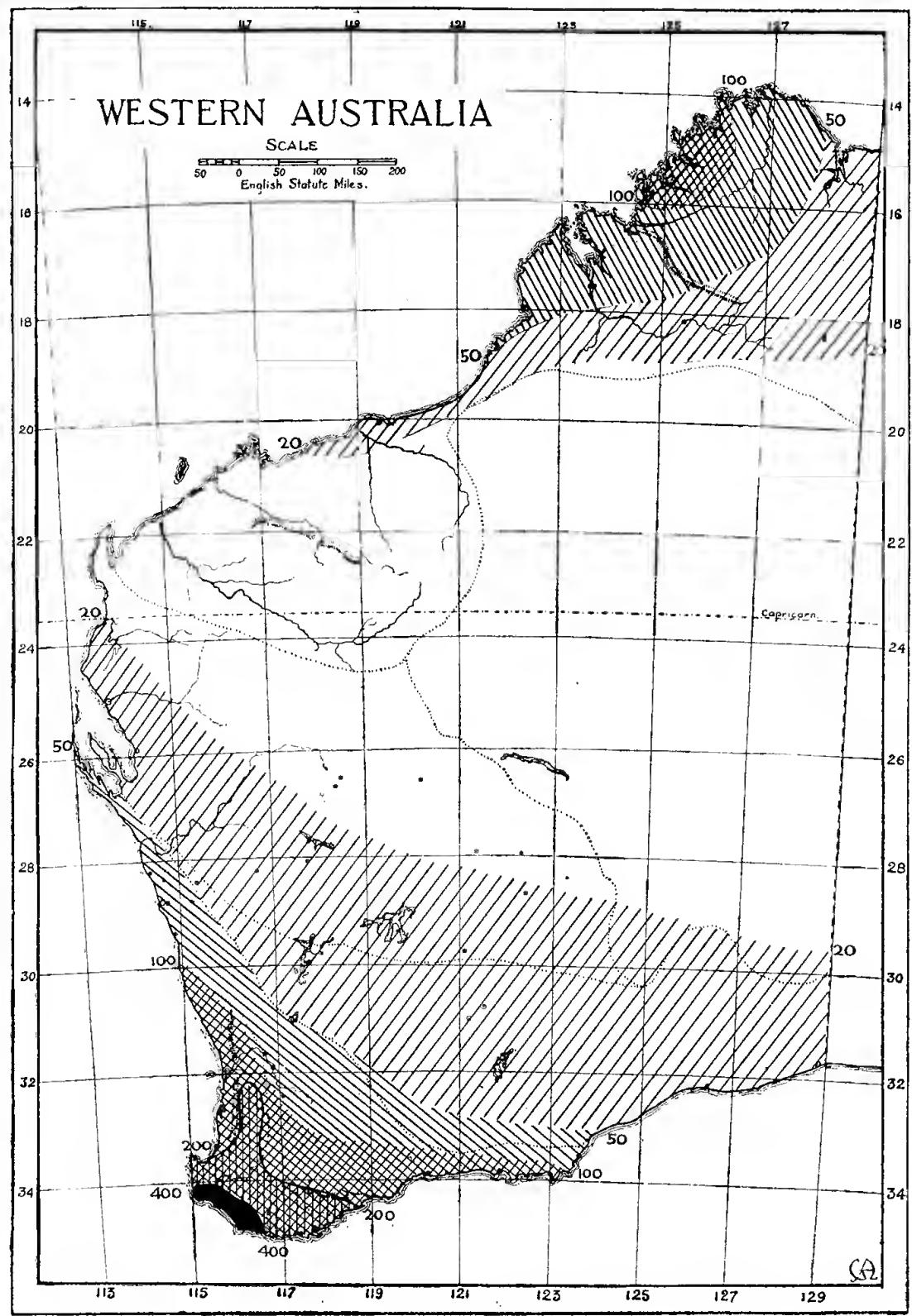


PLATE VI.

MEYER RATIO.

$$\left(\frac{P}{SD}\right)$$

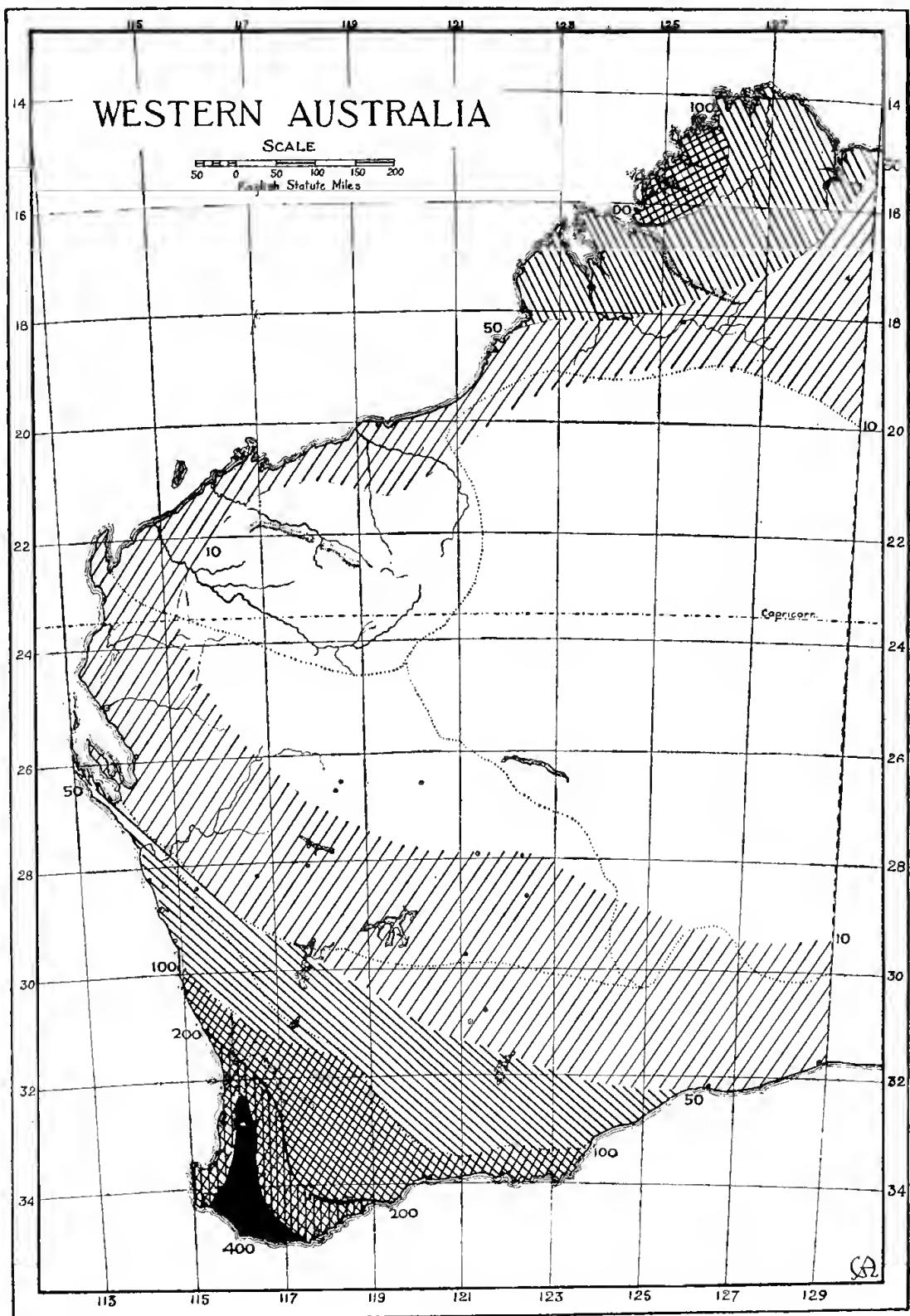


PLATE VII.

The Seasonal Precipitation. Ratio.
Seasonal saturation deficit

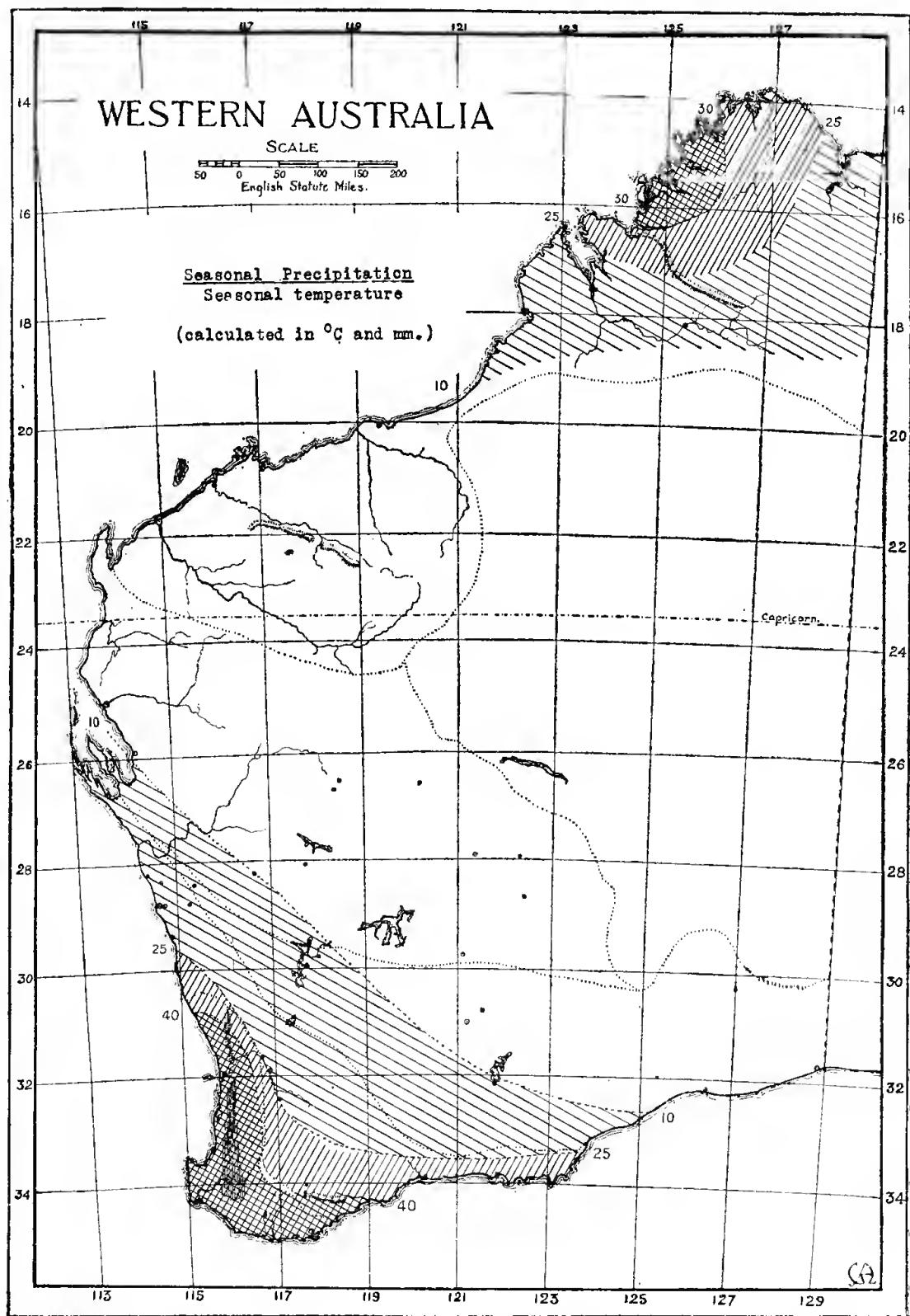


PLATE VIII

The Seasonal Precipitation Ratio.
 Seasonal temperature
 (Calculated in °C. and mm.)

PLATE IX.

THE THREE PROVINCES OF VEGETATION AND CLIMATE.

1. *The Northern Province.*—Summer rainfall-winter drought. The four consecutive wettest months are December-March or January to April, the precipitation for these four months being in excess of 175 mm.
2. *The South-West Province.*—Winter rainfall-summer drought. The four consecutive wettest months are May-August, the precipitation for this period being in excess of 175 mm.
3. *The Eremean Province.*—Rainfall for the four consecutive wettest months being less than 175 mm. In the northern part (indicated by broken lines), the four wettest months are January-April. In the southern part (indicated by broken lines) the four wettest months are May-August. The middle region (unhatched) has its maximum precipitation between March and June, the two wettest months being March and June.

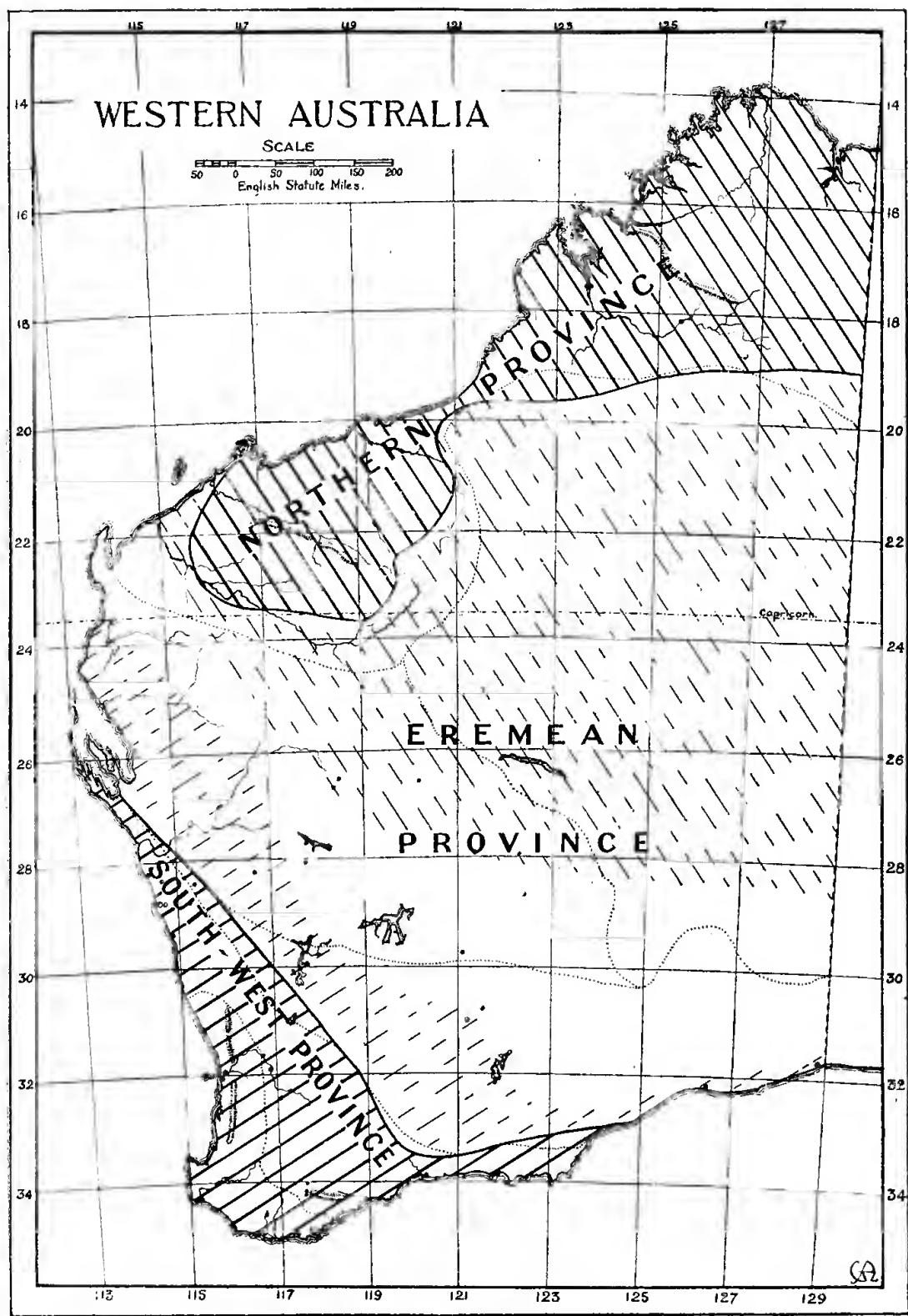
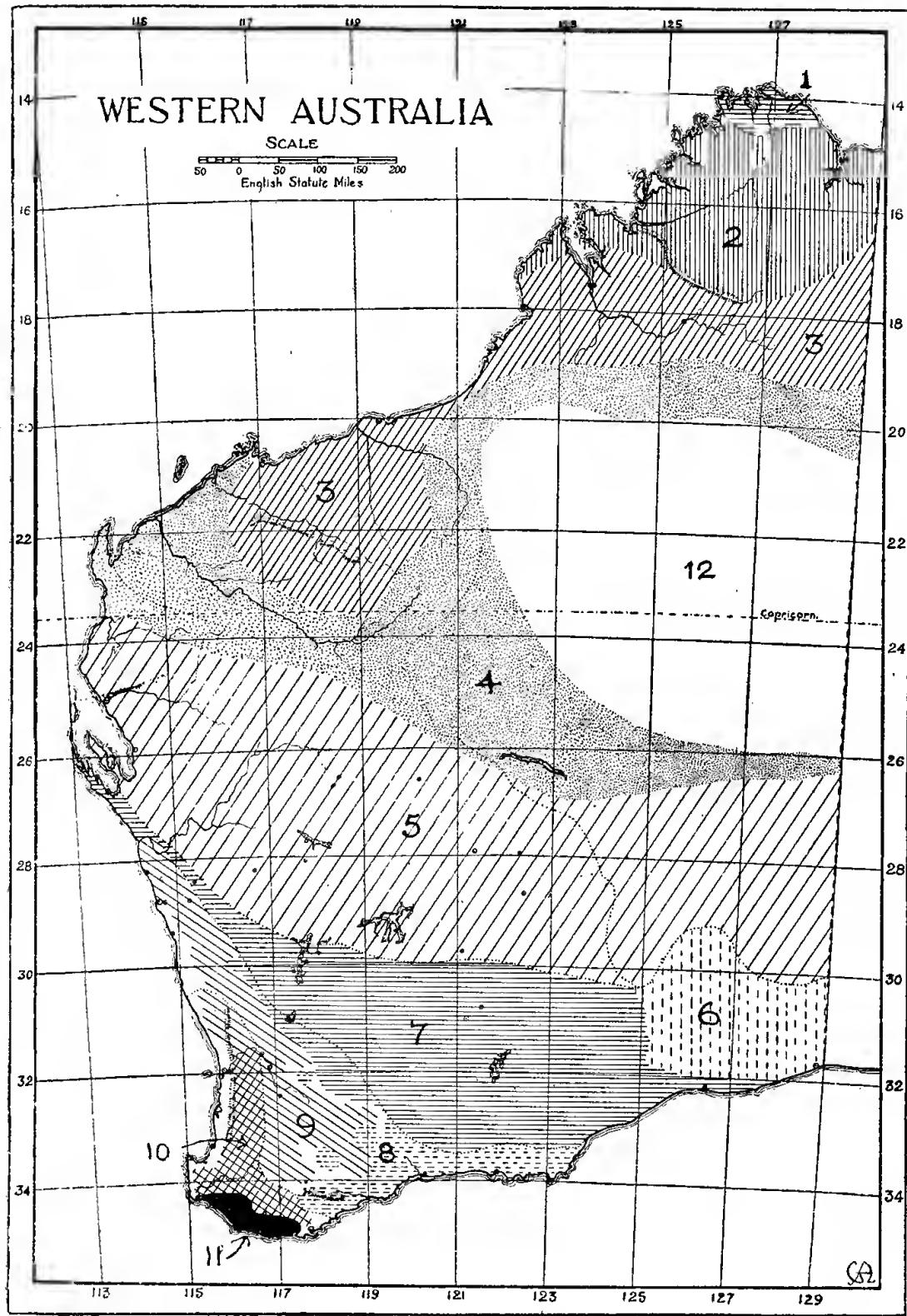


PLATE X.

THE FORMATIONS OF THE VEGETATION.

1. Tropical sclerophyllous woodland.
2. Monsoon woodland, savannah woodland, and riverain forest.
3. Savannah and open savannah woodland.
4. Triodia steppe.
5. Mulga Bush.
6. Salt-bush steppe.
7. Sclerophyllous woodland.
8. Sand-heath.
9. Temperate savannah woodland.
10. Sclerophyllous forest ("Jarrah forest").
11. Mesophytic forest (Karri forest).
12. Desert.



JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA.

VOLUME XXVIII.

1.—PERMIAN PRODUCTINAE AND STROPHALOSIINAE OF WESTERN AUSTRALIA.

By K. L. PRENDERGAST.

Read 8th October, 1941; Published 20th April, 1943.

Communicated by Professor E. de C. Clarke.

CONTENTS.

	Page
I. Introduction	1
II. Morphology and Bionomical Interpretation thereof	2
III. Trends in the <i>Productinæ</i>	8
IV. Classification	9
V. Description of Species	12
VI. Bibliography	57
VII. Plates	62

I. INTRODUCTION.

The correlation of beds in geographically distant localities has often been based on the comparison of published lists of fossils. At many times in the history of Australian Geology these comparisons have been made without a re-examination of the specimens concerned:

“Creatures borrowed and again conveyed
From book to book—the shadows of a shade.”

The first specimens from Western Australia were described in 1883, and at that time one specific name covered a multitude of forms which have now been subdivided into several species. It is thus obvious that if the correlations are to have any value, drastic revision of the naming of many specimens is necessary. This paper, containing complete descriptions of the Permian *Productinæ* and *Strophalosiinæ* of Western Australia is a small contribution towards that revision.

The present time is opportune for this revision as the work of the geologists of the Freney Kimberley Oil Co. and of Oil Search, Ltd., has increased enormously our knowledge of the geology of the Permian and has made available collections of fossils. I offer my thanks to Dr. Arthur Wade of the Freney Kimberley Oil Co. and to Mr. H. Fleteher of the Australian Museum, Sydney, for the loan of the specimens collected.

For the loan of specimens used in the preparation of this paper the author thanks, as well as those already mentioned, Dr. H. M. Muir-Wood of the British Museum, Professor E. de C. Clarke of the University of Western Australia, Mr. A. G. Brighton of the Sedgwick Museum, Cambridge, Mr. L. Glanert of the Western Australian Museum and Mr. F. G. Forman of the Geological Survey of Western Australia. From Dr. Muir-Wood, Mr. Brighton, Professor Clarke and Professor Wanner of Bonn I have received

much helpful advice. The text-figures have been drawn by Dr. D. H. Rayner and the photographs prepared by Mr. A. Barlow of the Sedgwick Museum and Mr. H. Smith of the University of Western Australia. The author gratefully acknowledges her indebtedness to these persons and to many others, too numerous to name, who have given her assistance.

The work has been done while the author held a Hackett Studentship of the University of Western Australia and an 1851 Overseas Scholarship. She records here her thanks to the authorities concerned in these awards.

The publication of this paper has been made possible by a grant from the Hackett Studentship Fund of the University of Western Australia.

The following abbreviations are used in the text:—

B.M., British Museum (Natural History).

Aus. Mus., Australian Museum.

W.A. Mus., Western Australian Museum.

U.W.A., Department of Geology, University of Western Australia.

G.S.W.A., Geological Survey of Western Australia.

The terminology as used throughout this paper is as defined by Muir-Wood (1928). All measurements of specimens are given in millimetres and the sign + after a number indicates measurement along a broken specimen.

II. MORPHOLOGY AND BIONOMICAL INTERPRETATION THEREOF.

External Features.

The general form of the shells of the *Productinae* and *Strophalosiinae* is concavo-convex dorso-ventrally. There are, however, some exceptions.

Within the group *Productus* sensu lato the concavity of the brachial valve varies from strongly concave as in *Krotovia* to almost flat as in *Waagenoconcha*. The pedicle valve is always convex and usually strongly so. The curvature, as seen in longitudinal profile, may vary but little over the whole profile or may change abruptly. In the latter case the shell is called geniculate when the curvature has increased and fringed or flanged when it has decreased. Fredericks has suggested a classification of the Productids based on the types of visceral cavity produced by the differences in curvature of the two valves. He distinguishes three types.

A. *Productus typici* a. Pedicle valve with regular curvature. Brachial valve flat or gently concave. Visceral cavity deep. e.g. *Waagenoconcha imperfecta* Prendergast.

B. *Productus typici* β. Pedicle valve with regular curvature. Brachial valve concave, following the curve of the pedicle-valve. Visceral cavity thin. e.g. *Krotovia spinulosa* (Sowerby).

C. *Productus proboscidci*. Pedicle valve regularly curved or geniculate. Brachial valve geniculate. Development of trail characteristic of the group. e.g. *Productus productus* (Martin).

The terms suggested by Fredericks serve as useful names for the description of visceral cavities, but it is doubtful if they can be used as the diagnostic feature by which to distinguish separate genera. The character of the visceral cavity may or may not be a reflection of important anatomical differences. It is, however, of little importance in modern lamellibranchs as *Pecten*, for example, has one valve (usually the left) flat, while the right valve may vary from slightly convex to rotund. There is here, within the one genus, a great variation in the size of the visceral cavity. The example chosen may not be strictly analogous, however, and where in a large number of specimens the visceral cavity is of the same type, this, in combination with other features, could certainly be used as a feature of diagnostic importance.

In *Aulosteges* the shell has the same form as in *Productus* s.l. Where, however, the area of the pedicle valve is high and reclined, this valve tends to become flattened and the brachial valve is slightly convex, the form approaching to the condition seen in the *Orthotetinae*. Among the species of *Strophalosia* the form of the shell does not vary beyond the limits already described for *Productus* s.l. In *Etheridgina* the pedicle valve is often flattened by attachment of the whole valve.

The area of attachment in *Strophalosia* and *Aulosteges* raises the question of the position of the shell during life. In *Productus* s.l. the shell lay on the larger pedicle valve with the brachial valve approximately parallel to the substratum and the plane of symmetry vertical. The growth of a trail allowed the animal to obtain its water supply from a level higher than that of the body. Possibly the shell sank by its weight into the substratum and water taken into the body through the trail was cleaner and contained a richer food supply. The trail would also serve as a protection to the animal in providing only a narrow opening at some distance from the vital organs and separated from them by a right-angled bend. In *Strophalosia* the point of attachment is at the apex of the umbo. It is not known for what period of its life the animal was attached, but it seems unlikely, when the small size of the cicatrix is compared with the size of the shell, that this condition of growth prevailed throughout life. However, whatever the length of this period the shell must have grown upwards from the point of attachment at the umbo. In many *Strophalosias*, owing to the geniculated or bevelled character of the interior of the brachial valve the shell develops a small trail. Presumably, when the shell became too heavy to maintain itself in the vertical position it fell on to its heavier pedicle valve, the trail then serving as in *Productus*. An irregular deformation of the umbo, presumably due to attachment, is sometimes seen in *Aulosteges*; the same explanation may be offered in this genus.

The ornamentation of the *Productinæ* and *Strophalosiinæ* is essentially spinose. Spines are developed most frequently on the pedicle valve and rarely on the brachial valve which, where the pedicle valve is spinose, develops pits corresponding in position to the spines of the pedicle valve. The spines may be of one or different sizes, they may be erect, oblique or adherent while their position on the shell may vary from genus to genus. They may be scattered irregularly or show a definite arrangement such as a row along the cardinal margin or separating the ears from the body of the shell. They may occur in concentric or radial rows or show a regular quincuncial arrangement over the whole shell surface. The capacity to develop spines is probably

inherent in the animal, while the degree of their development will depend upon external environmental conditions. Given the condition necessary for spine development, that is, a plentiful supply of CaCO_3 , any species will probably develop spines in the same position in all its members. The inclination of the spines to the body surface will depend upon the hardness of the sea-floor, arising at a high angle where the substratum is soft and being adherent where it is hard. In modern lamellibranchs the temperature of the water has a marked effect on the thickness of the shell, the Arctic forms having a thick shell and the warm water forms of the same species a shell thin almost to fragility. The difference between the Irwin forms, thin with short spines of small bore and those from Mt. Marmion, thick-shelled with heavy spines, of *Tæniothærus subquadratus* (Morris) is possibly due to the difference in temperature of the sea at the two localities.

Both valves may be ornamented by rugæ and costæ. The rugæ are formed at the growing edge of the shell and are thus in inverse positions in the two valves. Costæ are longitudinal folds perpendicular to the rugæ. Where both are present, the surface is reticulated as seen in the *Dictyoclostus* group; at the points of contact of the two series of folds an enlarged node may be produced, sometimes giving rise to a spine. Wrinkles are more indefinite than rugæ, they may cross the visceral disc or be confined to the ears. The lamellæ seen in *Strophalosia* and *Aulosteges* are quite distinct from both rugæ and wrinkles. They are not folds but are the edges of the shell as it was laid down in successive layers. The distinctness of these layers one from another indicates that secretion of shell substance was not continuous but intermittent and seasonal, a period of secretion being followed by a resting phase. The control is a physical one but the response of the various genera is dependent on the sensitivity of the animal itself and is, therefore, a biological factor.

In the structure of the cardinal margin these shells show a wide diversity of form. In the *Productus* s.l. group a cardinal area is not ordinarily developed. In *Dictyoclostus callytharrensis* n.sp. however, and in some Indian forms, e.g. *Dictyoclostus indicus* (Waagen) a narrow concave "area" named by Schuchert and Cooper a ginglymus is often seen on the pedicle valve. It is to be noted that the ginglymus is only seen when the brachial valve has been displaced. This ginglymus is a groove along the cardinal margin of the pedicle valve into which fits the narrow margin of the brachial valve hence greatly increasing the efficiency of the articulation of the valves. In the genus *Productorthis* Schuchert and Cooper postulate that the ginglymus has arisen from the degeneration of the area. This explanation cannot hold for *Dictyoclostus*, as the early forms of the genus possess neither an area nor a ginglymus. Whether the ginglymus can, conversely, develop into an area, present information does not allow us to state. It seems unlikely that development would take this course unless teeth are present to take over the function of the ginglymus as an aid to articulation.

Both *Aulosteges* and *Strophalosia* possess a true area though its form is very different in the two genera. In *Aulosteges* it is linear in the earlier species, but rapidly develops among the later species to a high plane triangle produced ventrally and thus carrying the umbo of the pedicle valve away from the brachial valve. In *Strophalosia* the area is much smaller, remains linear throughout the genus and is produced over the hinge-line so that the umbo of the pedicle valve approaches the brachial valve. A narrower area is present in the brachial valve of *Strophalosia*.

The area in both these genera possesses a distinct pseudo-deltidium and in *Strophalosia* a pseudo-chilidium in the brachial valve. The terms pseudo-deltidium and pseudo-chilidium have not the significance usually given them in the description of embryonic brachiopods. The division of the area into two lateral parts by the pseudo-deltidium is undoubtedly due to the interruption of the deposit of CaCO_3 along the cardinal margin by the projecting ridges, the pseudo-deltidium being that part of the shell filling the space between these ridges. At the places of formation of the ridges there is excess CaCO_3 deposit and this projects slightly above and below the level of the area, as Frederick's "delthyrial ridges" above and where the downward projecting ridges are more pronounced they take on the function of and are, teeth. In *Strophalosia* the angle of divergence of the sides of the pseudo-deltidium gives some indication of the angle of divergence of the roots of the teeth though not necessarily of the teeth themselves as these may extend laterally from their roots. That portion of the hinge-area, called, in the brachial valve, the pseudo-chilidium is the posterior root of the cardinal process. The narrow grooves limiting its extent are the internal edges of the sockets. In *Aulosteges*, which has no brachial area, the posterior root of the cardinal process is produced beyond the hinge-line as a flat triangular plate, in the plane of the brachial valve, which partly fills the delthyrium. The pseudo-deltidium of *Aulosteges* may bear spines.

Internal Features.

Brachial Valve.—However the external appearance of the brachial valve may vary on the inside it always has a flat visceral disc with possibly down-turned margins. A medium septum arising at the base of the cardinal process divides the shell into two halves. The septum varies in length from one-half to two-thirds of the length of the visceral disc.

Muscle Impressions.—The adductor muscle impressions lie posterior to the middle of the valve on either side of the median septum. They are dendritic in *Aulosteges* and *Productus* s.l. but non-dendritic in *Strophalosia*. The presence of dendritic muscle impressions in *Aulosteges* and *Productus* s.l. is a reflection of the poorly developed articular apparatus in these two genera. Since the brachial valve is pivoted loosely on the cardinal process it is capable of movement not only in a plane perpendicular to the surface of the valve but also from side to side. This lateral skewing movement would cause a differential movement within the muscle itself, the fibres nearer the centre being less extended than the eccentric fibres. A divided muscle would, therefore, be mechanically superior. In examining a dendritic muscle it will be noted that the bunches of fibres have an approximately radial arrangement with the radii on the inside much shorter than those towards the lateral margin. As the central muscles have a shorter pull this arrangement is what would be expected.

In *Strophalosia* the muscle scars are non-dendritic but, except in *Wyndhamia*, are divided into posterior and anterior parts. The anterior adductor is elongated in the longitudinal axis of the shell and lies very close to the median septum while the posterior portion is elongated laterally, lies above and close to the anterior adductor, but extends beyond it. The brachial impressions arise at the lateral terminations of the posterior adductor impressions.

Brachial Impressions.—The brachial impressions are similar throughout the group. In *Strophalia*, as already noted, they arise at the lateral extremities of the posterior adductors and continue to the lateral margin at an angle to the hinge-line varying from 45° - 0° . They then run parallel or nearly so to the lateral and anterior margins to a point about one-third of the width of the shell from the lateral margins when they curve through a right angle towards the hinge-line. This line is followed until the impressions are opposite the end of the median septum where they have another right angle bend to meet at the anterior end of the median septum. In *Productus* s.l. and *Aulosteges* the brachial impressions arise at the anterior end of the dendritic impressions and continue to the lateral border in a course parallel to the hinge-line. When almost at the lateral margin they curve in a wide arc and return to the base of the median septum, again running parallel to the hinge-line. In many specimens the returning arm is but faintly seen or may be totally obscured. The interpretations of the brachial impressions have been numerous. They are now described as the attachments of the brachial arms which projected ventrally from them. Muir-Wood (1928, p. 20) has cited some evidence in favour of this view from the minute structure of the impressions. The upward medial bend, where the impressions recede from the anterior margin would correspond, then, to the pallial sinus of the Lamellibranchs, being the region of water intake. The water would be ejected from the apices of the cones and this current would thus have no effect on the basal attachments. The development of a fold in the brachial valve with the corresponding sinus in the pedicle valve would serve further to localise the ingoing and outgoing currents.

Cardinal Process.—In the description of the species the term "trifid" has been used to describe the cardinal process. To avoid misapprehension that term is here defined as referring to a cardinal process which is bilobed in ventral aspect and trilobed in dorsal aspect or which is a modification of this type. The dorsal and ventral aspects are the views of the cardinal process as seen from the brachial and pedicle valves respectively.

To expand this definition the cardinal process of *Aulosteges wangenheimi* (Vern.) may be considered (refer to Fig. 5, p. 34). In this species the cardinal process is perpendicular to the plane of the brachial valve and is supported by two lateral ridges arising from the cardinal ridge. These ridges, which are separated medially by a deep sulcus, give rise to two convex masses, the lobes of the ventral aspect, separated by a depression. The dorsal aspect shows the structure of the process clearly. It has the form of a double-S. The median convexity of this double-S is the central lobe, and the end arms the lateral lobes of the dorsal aspect while the two concavities are the lobes of the ventral aspect. The whole process has the form of an open and indented cone with its apex at the hinge-line. The growth-lines of the structure may be followed round the dorsal face and are parallel to the base of the cone.

All the cardinal processes examined were modifications of this type. Thus in *Aulosteges baracooidensis* Eth. fil. the process is not in such an advanced stage of development. The dorsal aspect shows the process elongated with the lobes becoming distinct some distance from the hinge-line. The ridges of the ventral aspect have remained as ridges and are not enlarged into the convexities seen in *Aulosteges wangenheimi* (Vern.). They are indented posteriorly having a quadrilobed termination.

The variations within *Productus* s.l. are numerous. In the semireticulate group as Muir-Wood (1928, p. 18) says:—

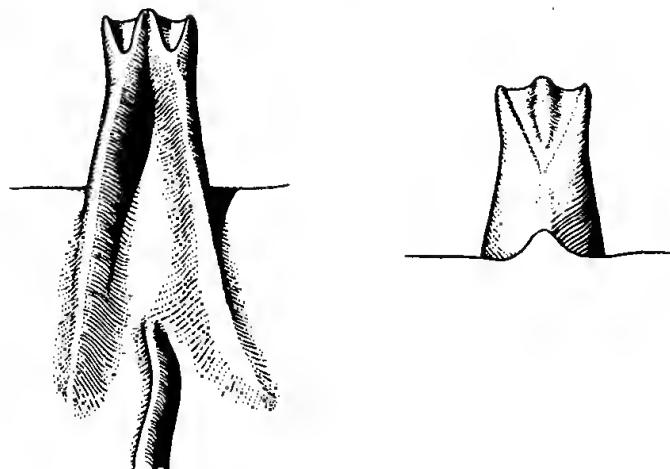


Figure 1.

Cardinal Process of *Aulosteges baracoodensis* Eth. fil. ($\times 3$).

"The cardinal process projects beyond the margin of the braeial valve and is divided by a median furrow into two parts which are smooth and rounded; these are continued dorsally as to two curved laminae, separated from the median septum by deep sulci. The dorsal view of the process shows it to be trilobate and transversely striated."

This condition can be readily understood by reference to Figure 2 (p. 15) showing the cardinal process of *Dietyoclostus callytharrensis* n.sp. In this species as in all Dietyoclostids the whole cardinal process is flattened and widened and the lateral lobes have been rotated through nearly 90° until, instead of being parallel to the central lobe, they lie at right angles to it and parallel to the hinge-line.

In *Taeniothaerus*, *Linoprotectus* and *Waagenoconcha* the modification has taken quite a different form, as in these genera the tendency has been for the process to elongate and for the lateral lobes to be distinct and separated from the central lobe (see *Taeniothaerus subquadratus* (Morris), Figure 3, p. 28). The median depression of the ventral aspect is distinct and continues to the apex of the process but the posterior part of the process is now trifid even in its ventral aspect. In *Taeniothaerus* the process is still compact, but in *Linoprotectus* (e.g. *Linoprotectus cora* (d'Orb.) Kozlowski, fig. 8, p. 14) the lateral lobes have splayed out and the process appears winged. In *Waagenoconcha* (e.g. *Waagenoconcha humboldti* (Waagen), Kozlowski, fig. 9, p. 15) the dissection of the lobes is continued further towards the hinge-line than in the other genera. In the aged specimens Kozlowski found that the median lobe sometimes divided giving what has been described as a quadrilobed cardinal process.

The shells so far considered have had the median septum separated from the cardinal process by a sulcus of varying depth. In the *Strophalosias*, on the other hand, the median septum arises within the cardinal process. The septum swells out between the sockets and completely fills the median depression between the ventral lobes. This swelling is shown in *Strophalosia kimberleyensis* n.sp. (Fig. 8, p. 48) in which a part of the depression may be seen posterior to it. This outgrowth of the median septum would give additional support to the socket plates. The median septum in *Strophalosia etheridgei* n.sp. (Fig. 7, p. 44) is not unduly swollen, but has, nevertheless,

completely obliterated the median depression. On its dorsal face, also, the process of this species is much reduced, faint depressions marking the positions of the dorsal concavities.

Where the median depression is present in the ventral aspect, as in *Aulosteges* and *Productus* s.l. the depth of this depression is regulated to some extent by the inclination of the cardinal process to the plane of the brachial valve. Where the process is erect the depression is shallow but where it becomes sharply bent over, as in *Aulosteges wangenheimi*, the sulus is very deep.

Marginal Ridges, etc.—Marginal ridges are sometimes developed in species of this group, for example, *Strophalosia kimberleyensis*. These ridges are always low and not prominent. In some species of *Aulosteges* a pronounced ridge may be developed along the hinge-line, as in *Aulosteges wangenheimi* (see Fig. 4, p. 33). This ridge is placed anterior to the hinge-line.

Pedicle valve.—The muscle impressions of the pedicle valve are of the same general form although they vary throughout the group. The adductors, dendritic in *Aulosteges* and *Productus* s.l., non-dendritic in *Strophalosia*, are median and separated by a groove or a small ridge. The diductors are large, flabellate and longitudinally striate. In some species of *Strophalosia* the ears of the pedicle valve are thickened so that when the shell is closed the ears fit closely one upon the other. This thickening is seen as a flat ledge on the inside of the valve and projects slightly over the visceral cavity.

For a description of the microscopic structure of the shell reference should be made to Muir-Wood (1928, p. 29) and Dunbar and Condra (1932, p. 179).

III. TRENDS IN THE PRODUCTINAE.

Although sufficient data are not yet available for the recognition of lineages, nevertheless some indication of possible trends can be given, based on the fauna of other areas, and these ideas can be applied to the Australian forms.

The table below shows the distribution and characters of the species of *Aulosteges* from the Permian of the Glass Mountains, Texas (King, 1930).

—	Wolfeamp.	Hess.	Leonard.	Word, Delaware Mtn, White Limestone of Guadalupe.
<i>A. wolfcampensis</i>	1b, 2b, 3b	....	....	....
<i>A. medlicottianus</i>	1b, 2b, 3b	1b, 2b, 3b	1b, 2b, 3b	1b, 2b, 3b
<i>A. magnicostatus</i> ....	....	1b, 2b, 3a	1b, 2b, 3a	1b, 2b, 3a
<i>A. triagonalis</i> ....	....	1a, 2b, 3a	1a, 2b, 3a	1a, 2b, 3a
<i>A. subcostatus</i> ....	....	....	1a, 2a, 3b	....
<i>A. beedei</i> ....	....	....	1a, 2a, 3a	1a, 2a, 3a
<i>A. guadalupensis</i> ....	....	....	....	1a, 2a, 3a
<i>A. tuberculatus</i> ....	....	....	....	1a, 2a, 3a

Where 1. radial costae ; b, present, a, absent.

2. concentric wrinkles ; b, present, a, absent.

3. area ; b, low and linear, a, higher and triangular.

As may be seen from the table the shells change from a lirate, concentrically wrinkled form with a low linear area to an unwrinkled form with a high triangular area ornamented only by spines and growth lines.

In India, the evidence of a parallel evolution of *Aulosteges* is not so clear, but is indicated. *Aulosteges medlicottianus* occurs in the lowest fossiliferous beds, the Amb, of the Salt Range, while *Aulosteges (Strophalosiina) tibeticus*, which has the same characters as *Aulosteges magnicostatus* (concentric wrinkles with radial costae anteriorly) is found in the Middle Productus limestone. *Aulosteges dalhousii* from the Upper Productus Limestone has the same characteristics as *Aulosteges guadalupensis*.

Among the Australian form a similar parallel can be traced. A series of forms appears connecting *Aulosteges baracoodensis* with *Taeniothaerus subquadratus*. The latter species has no concentric wrinkles, a low linear area and the spine bases on the anterior part of the shell sometimes elongated as radial ridges. *Aulosteges baracoodensis* is ornamented by spines and growth lines only, and has a higher triangular area. Both these end forms occur in the Fossil Cliff Beds, Irwin River, although in the North-West Basin *Aulosteges baracoodensis* does not appear until much higher in the sequence. Judged by the rate of change of the American forms *Taeniothaerus subquadratus* would appear in the equivalent of the Hess beds and *Aulosteges baracoodensis* not until the Word. The evolution of the forms may, however, have taken place at different rates in the two areas.

A second shred of evidence of the general stage of development of the Western Australian fauna is provided by the *Dictyoclostus* group. In that genus there is a marked tendency for the area of reticulate ornament to decrease as the species become younger. Thus in *Dictyoclostus semireticulatus* from the Lower Carboniferous of the British Isles the reticulation may be found over the whole shell though not as clearly marked anteriorly. In the Permian species, however, the reticulation is confined to the posterior part of the shell. *D. spiralis*, *indicus*, *vishnu*, *aratus* and *subcostatus* is an ascending stratigraphical series from the Salt Range (Waagen 1884) and shows a gradual decrease in the area of reticulation of the species in the order named. The Western Australian shells, *Dictyoclostus callytharrensis*, have the reticulation covering but a small area of the valve and possess a ginglymus while the ears are separate from the flanks. All these features are seen only among the younger members of the genus.

IV. CLASSIFICATION.

Family **PRODUCTIDAE** Gray, 1840.

In his original description of the family, Gray included the genera *Productus*, *Strophalosia*, *Chonetes*, *Leptaena*, *Orthis*, *Strophomena* and *Calceola*. King (1846, p. 94) restricted the family to those shells "distinguished by the form of the ovarian spaces and the presence of spines," and excluded the genera *Strophomena*, *Orthis*, *Leptaena*, *Chonetes* and *Calceola*. Gray (1848, p. 438) was opposed to this restriction and enlarged the family to its original content. Gray's opinion, however, was not widely accepted, and King's diagnosis became the diagnosis of the family.

It was accepted thus by Waagen (1884, p. 611) who said:—

“the most striking character is the existence of reniform prominent ridges on the inside of the dorsal valve, a character which in this strong and distinct development, is entirely restricted to the *Productidae*.”

Waagen subdivided the forms so characterised into two sub-families, *Chonetinae* and *Productinae*.

The *Chonetinae* were characterised by the presence of teeth and a cardinal area in the pedicle valve and of non-dendritic muscle impressions. This sub-family included the genera *Chonetes*, *Strophalosia*, *Chonetella* and *Daviesiella*. Most of these forms are free.

The *Productinae* were defined as Productids in which the pedicle valve is without cardinal teeth and the adductor muscle impressions are dendritic. Some of the forms are fastened by the entire pedicle valve or by spines. Waagen placed the genera *Aulosteges*, *Productella*, *Productus* and *Marginifera* in this sub-family.

Schuchert (1913, p. 389) changed the emphasis in King's diagnosis and defined the *Productidae* as “*Strophomenacea* with hollow anchoring spines.”

Schuchert also altered the content of the sub-families by using the means of attachment of the shell as the main diagnostic feature. Thus the *Chonetinae* became

“Productids with a few anchoring spines restricted to the ventral cardinal margin,”

and the *Productinae*

“Productids with the anchoring spines more or less abundant over the entire ventral and sometimes also over the dorsal valve,”

while he founded a new sub-family the *Strophalosiinae* to include

“Productids anchored to foreign objects by spines or by most of the ventral shell.”

Such a division of the *Productidae* is purely arbitrary and while it groups together forms superficially alike, makes no allowance for a similarity of external form due to growth under similar environmental conditions. The sub-family *Strophalosiinae*, for example, includes the genera *Chonopectus*, *Strophalosia*, *Aulosteges* and *Etheridgina*.

Strophalosia King, the type genus of the sub-family is an attached form, being cemented by the umbo of the pedicle valve and/or by spines. It has a well-developed area on each valve, non-dendritic muscle impressions and strong teeth. *Etheridgina* possesses an area only on the pedicle valve, teeth may be developed and the shell is cemented directly by part or the whole of the pedicle valve and by spines. The muscle impressions are as in *Strophalosia*.

The genus *Chonopectus* Hall and Clarke is represented by a single species *Chonopectus fisheri* Norwood and Pratten from the English River beds of the Kinderhookian (equivalent to K beds, Lower Carboniferous) of Burlington, Iowa, U.S.A. This species is essentially a small *Chonetes* with a distinctive ornamentation and attached at some period during its life history. It is a restricted form, both geologically and geographically.

Aulosteges Helmersen is distinct from *Strophalosia* in the possession of dendritic muscle impressions. The pedicle valve carries an area, usually high, while that of the brachial valve is small or absent. The articulation is weak, the pedicle valve being without teeth.

It is obvious, then, that within his sub-family *Strophalosiinae* Schuehert has included forms very different in structure. Its attached habit seems an insufficient reason for the separation of *Chonopectus* from those forms, the *Chonetinae*, to which it is closely related, and Schmidt's placement of it (1929, p. 21) in that sub-family must be regarded as the more correct. *Aulosteges*, both in the possession of dendritic muscle impressions and in the pattern of the brachial impressions, approaches more closely to the *Productinae* than to *Strophalosia* and its replacement in the *Strophalosiinae* would seem a more natural position.

It is admitted, however, that little is known of the derivation of *Aulosteges* and *Strophalosia*. Licharew (1934 (a), p. 509) has, on the ground of insufficient evidence for their separation, abolished the sub-families and included all the genera in *Productidae*. He reverts to King's diagnosis and defines the family as

"Shells free, attached by spines or cemented directly. Dorsal valve flat or eoneave. Cardinal margin straight. The whole surface or only the shoulders of the ventral valve bedecked with hollow spines. Cardinal process prominent. Dorsal valve with reniform brachial impressions."

To *Productus* sensu lato, *Chonetes* sensu lato, *Strophalosia*, *Productella*, *Aulosteges* and *Etheridgina* he adds *Teguliferina* and *Scacchinella*. Dunbar and Condra (1932, pp. 189, 191) and Diener (1927, pp. 30 and 31) also included these genera in the *Productidae*.

Scacchinella Gemmellaro and *Teguliferina* Schellwien are the genera intermediate in character between *Aulosteges* and *Productus* respectively and the *Richthofeniidae*. These genera, however, possess characters which would ally them to the *Richthofeniidae* rather than to the *Productidae*. *Scacchinella* and *Aulosteges* possess in common the high produced area (higher and more produced in *Scacchinella*) and the method of attachment by the tip of the area. *Scacchinella* is quite distinct, though, in the possession of a well-developed median septum in the pedicle valve and in the character of the cardinal process with its supporting rods. In these characters it approaches *Richthofenia*. *Teguliferina* in which the productoid characters are still recognisable, resembles closely the *Richthofeniidae* in its mode of growth and in the operculiform character of the brachial valve. It seems reasonable to assume that the peculiar characters of *Richthofenia* are in part a result of its mode of growth and therefore that *Scacchinella* and *Teguliferina*, as the possible forerunners of a group so distinctive as the *Richthofeniidae*, should be included in that family.

A different method of approach to this subject of the classification of the *Productidae* has been used by Sutton (1938), with astounding results. As he points out, the shape of the visceral cavity as a diagnostic feature has been given prominence in Productid literature although no author has attempted a classification based upon that feature. Sutton has. He divides the Mississippian *Productidae* into two sub-families, the *Productellinae* and the *Productinae*. The *Productellinae* have a thin visceral cavity of the type described by Fredericks as *Productus typici* β , and include the genera

Leptalosia, *Strophalosia*, *Productella*, *Gigantella* and *Productina* Sutton. The remaining Productid genera of the Mississippian rocks are grouped as the *Productinae* and possess in common a "large and medium to deep visceral cavity—Frederick's *Productus typici* α."

This cannot be regarded as a biological or palaeontological classification; it is as Sutton (p. 538) says, "a classification by which different forms may be recognised," in other words, a key, and a key only for the Mississippian *Productidae*. Sutton supports this "classification" by reference to one now being worked out by Stoyanow, who is using as a diagnostic feature the character of the cardinal process, whether trifid or bifid. Examination of the Australian Productids shows that all have essentially the same type of cardinal process, but Stoyanow will doubtless define his terms more accurately when his paper is published.

In the classification which follows the author has tried to group closely related forms together, and finds that in so doing he has reverted largely to Waagen's original diagnoses of the sub-families while following Liebherr in the definition of the *Productidae*.

Family *Productidae* Gray 1840. Synopsis of the contents of the British Museum, 42nd Edition, p. 151.

Shells free, attached by spines or cemented directly by pedicle valve. Cardinal margin straight. Surface ornamentation of spines over whole or part of shell. Brachial valve with reniform brachial impressions and median septum. Cardinal process prominent.

Sub-family 1. *Chonetinae* Waagen 1884. Salt Range Fossils, I. Productus-Limestone Fossils: IV (fasc. 3) Brachiopoda, *Pal. Ind. Ser. XIII*, p. 612.

Productids with large spines only along cardinal margin of pedicle valve. Cardinal area and teeth in pedicle valve. Muscle impressions non-dendritic.

Genera. *Chonetes* sensu lato.
Chonopectus.
Daviesicella.

Sub-family 2. *Productinae* Waagen 1884, op. cit., pp. 612, 613. Productids with dendritic muscle impressions and without teeth. Hollow spines present over whole or part of shell.

Genera. *Productus* sensu lato.
Productella.
Aulosteges.

Sub-family 3. *Strophalosinae* Schuchert 1913, in Zittel K., Textbook of Palaeontology edited by C. R. Eastman, 2nd edition p. 391.

Productids attached by spines and by part or whole of the pedicle valve. Ornamentation usually spinose. Muscle impressions non-dendritic. Pedicle valve with cardinal area and teeth.

Genus. *Strophalosia*.
Heteralosia.

V. DESCRIPTION OF SPECIES.

DICTYOCLOSTUS Muir-Wood emend.

1930. Muir-Wood, *Ann. Mag. Nat. Hist.* (10) V p. 103.

Genotype.—Original designation. *Anomites semireticulatus* Martin (in part). *Petrifacta Derbiensis*, Wigan 1909, p. 7, pl. xxxii, figs. 1, 2; pl. xxxiii, fig. 4.

Diagnosis.—Shell elongate or quadrate in outline, hinge wide; ginglymus may be present. Pedicle valve convex or geniculate; visceral disc with semi-reticulate ornamentation; trail costate, costae may bear spines both on trail

and visceral disc; rows of spines on ears and cardinal slopes; diaphragm absent. Brachial valve concave or geniculate; marginal ridges prominent, extending along hinge. Hinge teeth and sockets not developed.

Range.—Carboniferous and Permian.

Remarks.—The diagnosis has been emended to include semireticulate productids with a ginglymus (see p. 9). The Western Australian, Timor and Indian species which would normally be placed in this genus are sometimes found to have a ginglymus though agreeing in other particulars with species of this genus. Where the margin is interrupted by the cardinal process, the ginglymus is notched to give the "delthyrium," into which the cardinal process fits, as previously suggested by Dunbar and Condra (p. 18). Below this notch and on each side, thickened ridges which gradually die out laterally, articulate with the transverse ridges of the brachial valve. As would be expected, the ginglymus is not seen if the two valves fit tightly, but is only exposed when the brachial valve is slightly displaced. This was proved in a specimen (S.M. No. 3604) of *Dictyoclostus indicus* (Waagen) from the Salt Range; it possessed both valves, and was without an area, but showed an internal groove in that position when the brachial valve was removed.

The ginglymus has been noted in one other genus, *Productorthis* of Schuchert and Cooper (1932, p. 83). In *Productorthis*, Schuchert and Cooper believe that the ginglymus has arisen from the reduction of the area. In Productids it seems more likely that the area arose from the ginglymus.

The Permian species of *Dictyoclostus*, as far as can be seen from a study of the literature, differ from the Lower Carboniferous species in the restriction of the reticulation to the posterior part of the shell, the separation of the ears from the flanks and the possession of an articulating "area."

The larger Western Australian members of the genus *Dictyoclostus* are undoubtedly closely related, probably in the same way as the *spiralis-subcostatus* group of the Salt Range, and it is only lack of sufficient material which prevents the appreciation of their relationships.

Dictyoclostus callytharrensis sp. nov.

Pl. i, figs. 1-7, Pl. ii, fig. 1.

1903.—*Productus semireticulatus* Martin, Etheridge, jun., p. 18, pl. ii, figs. 3-5.

1907.—*Productus semireticulatus* Martin, Etheridge, jun., p. 29.

1910.—*Productus semireticulatus* Martin, Glauert, p. 87.

1924.—*Productus semireticulatus* Martin, Chapman, p. 36, specimens Nos. 2746, 2748.

1931.—*Productus semireticulatus* Martin, Hosking, pp. 8, 22.

Types.

Syntypes.—G.S.W.A. 1/4967 (b), $\frac{1}{2}$ mile west of Callytharra Spring, Wooramal River District; Callytharra Limestone.

Paratypes.—G.S.W.A. 1/4967 (a), same locality and horizon.

Other specimens.—U.W.A. 12400, Fossil Cliff, Irwin River; Fossil Cliff horizon.

G.S.W.A. 1/4668, south bank of Wooramal River, $\frac{1}{4}$ mile above Callytharra Spring; Callytharra Limestone.

G.S.W.A. 1/4654,

Aus. Mus. F 36507, 36508, Barragooda Pool, Arthur River, North-West Division. Callytharra Stage.

Aus. Mus. F 36237, Jimba Jimba Station, left bank of Gascoyne River, near Winnemia, North-West Division. Byro Stage.

Aus. Mus. F 38147, $1\frac{1}{2}$ miles west of Williambury-Middalya Gate, Middalya Station. Callytharra Stage.

Diagnosis.—Shell large, semicircular in outline, greatest width at hinge-line; ears large and reflexed, offset from flanks, flanks convex to steep. Pedicle valve sinuate, regularly curved through 270°. Visceral disc occupying about half curvilinear length of valve, rugae and costae regular and equally prominent on visceral disc, costae becoming irregular on trail, two or more coalescing to form irregular folds; rugae absent on trail. Small spines, quincuncially arranged, arising at intersection of costae and rugae, with larger spines, more widely spaced, on rest of shell. Row of spines between ears and flank and row along cardinal margin.

Brachial valve geniculate; ornamentation as in pedicle valve.

The size of the specimens is shown by the table:—

—	Syntypes.	Paratypes.	Largest spec., Irwin R.— 12400.
Length of hinge-line	59 59	58 44+	49+
Height	37 38	33+ 33+	46+
Curvilinear length	70 71	50 50	95

SHELLS too crushed to allow measurement of thickness.

Description of the syntypes.—Shell semicircular in outline with the hinge the greatest width of the shell.

The pedicle valve is curved through an angle of 270°. The transverse curve of the valve is a high arch with almost vertical sides and a shallow median depression. A shallow sinus arises at about the middle of the visceral disc and continues forward, becoming shallower and finally disappearing on the trail thus leaving the margin of the valve entire. The ears are large and reflexed; each is separated from the body of the shell by a sulus, and this is flanked by a fold bearing a row of spines (3-4). A second row of spines runs parallel to the hinge-line and close to it. The semireticulation is marked on the visceral disc, covering 35 mm. along the curvilinear length, the costae and rugae being equally prominent. The costae cannot be traced to the tip of the umbo, where they have been probably removed by weathering, but traces of them can be seen on the ears. They increase in number on the visceral disc both by division and by intercalation; no increase takes place on the trail and the costae lose their height, remaining scarcely elevated. The rugae are closely spaced near the umbo, becoming farther apart posteriorly. The spines on the visceral disc are small and oblique and arranged in approximate quincunx, each spine arising from a node at the intersection of a ruga and a costa. Spines do not arise from all the nodes. As the spines are regularly spaced and the number of costae increases anteriorly, there is some irregularity, but every fourth to sixth ruga bears spines, these being separated by eight or more costae. The larger spines on the trail also tend to quincuncial arrangement. Below each on the trail is a fold which replaces the two or more costae above each spine, this folding being independent of the costae, though two or more are absorbed on each fold.

The brachial valve is strongly geniculate. The ornamentation differs from that of the pedicle valve only in the absence of spines. The pits, which replace the spines on this valve, are not placed opposite them, but appear anteriorly. This is particularly noticeable in the row of pits on the sulcus separating the ears. No trace of a cardinal area has been observed on this valve.

The interior of the valve is not seen on the syntypes.

Description of the paratypes—Internal features.—The paratypes show the ginglymus more clearly than either of the syntypes. It is divided by a wide triangular notch. The cardinal process of the brachial valve projects but a little above the level of the hinge as a truncated triangular ridge.

Internally the muscles of the pedicle valve are those characteristic of the genus, longitudinally striated diductors enclosing dendritic adductors, the place of insertion of the muscle much thickened.

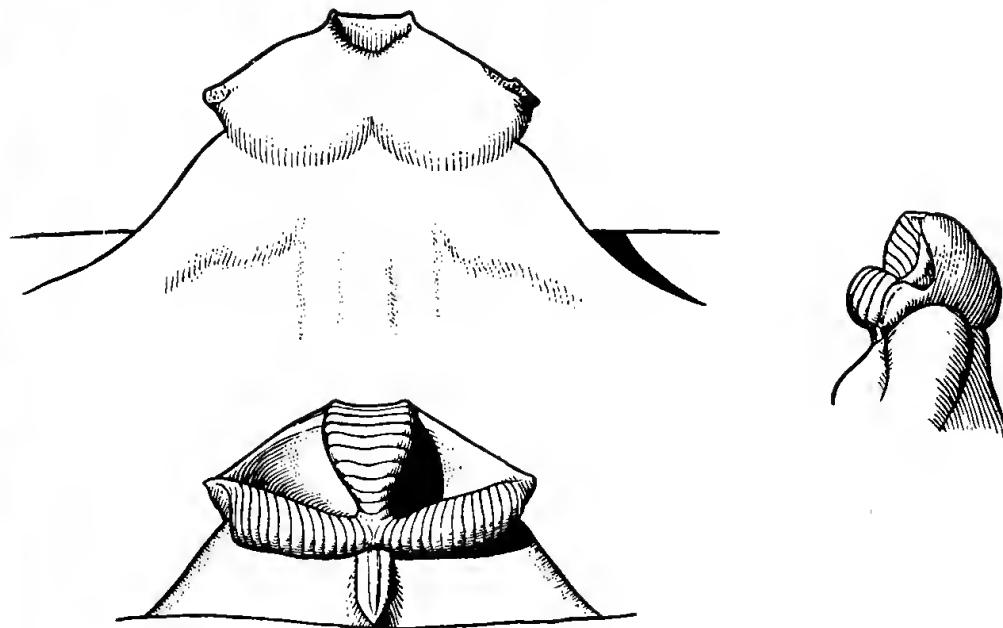


Figure 2.
Cardinal process of *D. callytharrensis* sp. nov. (x6).

Variation within the species.—The topotypes of this species show marked variation in the depth of the sulcus between the viseeral disc and the ears. When the sulcus is shallow and not pronounced the rugae extend on to the ears so that these are semireticulate. This extension of the semireticulation has an effect on the size of the auricular spines, since where the rugae are present the spines are small and similar to those of the viseeral disc, these replacing the larger spines seen in specimens with a deep sulcus. Recognising this as a variation within the species it is then possible to include the two forms distinguished by Hosking (1933, p. 46) in the one species.

A second variable feature of the specimens is the extent of the semi-reticulation along the curvilinear length of the shell. Although owing to the crushing of many of the specimens it is difficult to determine the original shapes, it would seem that rugae are not developed after there is a change in the direction of growth, even where this does not amount to a geniculation. This relation between the shape of the shell and the ornamentation probably

exists throughout the semireticulate group. *Dictyoclostus semireticulatus* (Martin), for example, has semireticulate ornamentation throughout its growth, and no change takes place in the curvature.

The Irwin River specimens show the same range of variation as those from the type locality.

Comparison with other species.—The specimens of this species have little in common with *Productus (Dictyoclostus) semireticulatus* Martin s. str. to which species they have been previously assigned. They differ in having the brachial valve geniculate, the rugae restricted to the visceral disc, the arrangement of the spines on the visceral disc and the division of the ears from the flanks. Briefly the only characteristic common to both species is the presence of semireticulate ornamentation.

The species has much in common with Upper Carboniferous and Permian forms of India and China. It probably occurs in Timor (Basleo) as Broili's figures and specimens (1916 pl. exvi figs. 14-16) show the same characteristics as the Australian species and Broili gives a reference to Etheridge (1903) in his synonymy. Of the Chinese specimens *P. taiyuanaensis* Grabau as figured by Chao (1927 p. 30 pl. i fig. 10; pl. ii figs. 1-12; pl. viii fig. 16) from the Taiyuan Series is very close to *D. callytharrensis*. The costation of the Chinese shells is much coarser (the costae vary from 0.5 to 1.3 mm. in width as compared with 0.3 to 0.5 mm.), the larger spines are more numerous and more closely spaced, particularly the row along the inner edge of the ears where each spine touches its neighbour.

D. callytharrensis is undoubtedly related to the *P. spiralis-subcostatus* group from the Salt Range. Frech first suggested that the forms *P. spiralis* and *P. indicus* were possibly the younger and older specimens of the same species, and Broili supported this. More lately Cowper Reed (1931 p. 2) has suggested that the whole group, *P. spiralis*, *indicis*, *vishnu*, *aratus* and *subcostatus* are probably all members of one species group. The nearest form of this group to *D. callytharrensis* is *P. indicus*, but the Western Australian specimens may be distinguished from that species by the tendency in the Indian species for the costae to converge towards, and disappear in, the sinus. Also the spiral arrangement of the costae on the ears cannot be seen in the Australian specimens. The costation is much coarser in *P. indicus* (7 costae in 10 mm., 10 mm. from the umbo).

Dictyoclostus callytharrensis var. *wadei* var. nov.

Pl. II., figs. 2-4.

Holotype.—U.W.A. 20453, ferruginous limestone, two miles east 10° south of Mount Nicholson, Kimberley Division; Nooneanbah Series.

Topotypes.—U.W.A., A.58, A.59, A.65, same locality and horizon.

Diagnosis.—Shell as in *Dictyoclostus callytharrensis* but with approximately hexagonal outline and arched umbonal region. Ears reflexed but not offset from flanks. Pedicle valve sinuate, with semireticulation on almost one-third of curvilinear length of valve, costae irregular, prominent and enlarged on trail, converging towards sinus. Brachial valve unknown.

Description.—The holotype of this variety is a weathered and decorated specimen. It is 63.7 mm. wide at the hinge-line and 54.5 mm. long. The semireticulate ornamentation of the visceral disc is badly worn, but probably occupied about 34 mm. along the curvilinear length. The ears, though reflexed, are continuous with the anterior margin of the valve. The trail is ornamented

by large costae, variable in width, bearing large spine bases; these show no regular arrangement. The costae tend to approach and disappear in the sinus. Two large spines are on the ears and three on the flanks just above the angle separating the ears. There is no enlarged rib or hollow on which they are placed. The umbo is rounded and barely overhangs the hinge-line. The ginglymus, if present, is obscured by matrix.

Variation within the species.—Owing to the paucity of specimens (5) it is impossible to determine the limits of variation.

Comparison with other species.—This variety differs from *D. callytharrensis* in the shape of the ears (here continuous with the anterior margin but in *D. callytharrensis* distinct and joining the lateral margin about halfway down the flanks), the greater convexity of the flanks and the invariable appearance of a well-marked sinus in the pedicle valve. The folds, too, in this species are enlarged costae and not formed, as in *D. callytharrensis*, by two or more costae coalescing. In all these particulars they approach *P. indicus* Waagen, but continually differ in the much finer ornamentation.

It is possible that this form should constitute a distinct species, but in the absence of any definite knowledge of their stratigraphical relations to *D. callytharrensis* I have preferred to designate them as a variety. They are obviously closely related to *D. callytharrensis* mihi.

Dictyoclostus gratiosus (Waagen).

Pl. ii, figs. 5-7.

1884.—*Productus gratiosus* Waagen, p. 691, pl. lxxii, figs. 3-7.

1893.—*Productus gratiosus* Waagen, Rothpletz, p. 76, pl. x, fig. 15.

1916.—*Productus gratiosus* Waagen, Broili, p. 12, pl. exvi, figs. 4, 5, 7-13.

1927.—*Productus gratiosus* Waagen, Chao, p. 44, pl. iv, figs. 6-10.

1928.—*Productus gratiosus* Waagen, Hamlet, pp. 19, 20.

Material.—Aus. Mus.

F 37567— $\frac{1}{4}$ mile east of shale outcrop, Minilya River, North-West Division, Wandagee Stage.

F 37568— $\frac{1}{4}$ mile west of shale outcrop, same locality and horizon.

F 37569-37571—Bank of Minilya River, same locality and horizon.

Diagnosis.—Shell small to moderate in size, outline hexagonal. Pedicle valve inflated, geniculate; brachial valve concave. Greatest width at hinge-line, ears small and pointed.

Pedicle valve with flat visceral disc, shell geniculate. Ornamentation reticulate on visceral disc, costate on trail. Strong sinus. Small erect spines scattered on trail and alar extremities. Costae converging towards sinus.

Brachial valve concave with median fold. Ears excavated, smooth or lightly costate. Convergence of costae towards fold. Valve with reticulate ornamentation on posterior part of shell.

Internal characters not known.

Description.	Dimensions.				
Length of hinge-line	27·8	18·0+	16·6+	25·0	14·5+
Height	17·7	13·7	16·1	15·8	11·7+
Curvilinear length of pedicle valve	30·9	21·0	32·3	31·8	21·0

The shells are small to moderate in size as may be seen from the table of dimensions. They have an irregularly hexagonal outline when viewed from the pedicle side, with the hinge-line the greatest width of the shell.

The pedicle valve has a flattish visceral disc which, following the geniculation of the shell, passes into a regularly curved trail. Transversely the shell arch is high, indented medially by a strong median sinus and falling gradually to the lateral margins in a slightly convex slope. The umbo is small, pointed and slightly overhanging the hinge-line. The ears are small and pointed, they have a convex profile in longitudinal section. The ornamentation is reticulate on the visceral disc, the reticulation sometimes irregular due to the enlarged rugae on some specimens. The rugae do not develop anterior to the geniculation, the trail carrying costae and scattered spine bases. The latter are rarely numerous, not more than 4 or 5 being present. The costae converge slightly towards the sinus giving a very distinct and characteristic appearance to the shell.

The brachial valve is trapezoidal in outline, the long straight hinge-line and the anterior margin being the parallel sides. It is regularly concave with a median fold which expands towards the anterior margin. The ears are excavated to fit tightly with those of the pedicle valve. The ornamentation is reticulate over the posterior third of the shell, the rugae then develop irregularly and the ornamentation of the rest of the shell may be described as costate. The costae radiate from the umbo, those in the central part of the shell converging towards and finally coalescing on the median fold.

The internal features of this species are not shown by any of the Western Australian specimens.

Comparison with other species.—This species is distinct from other Western Australian semireticulate productids in its small size. The convergence of the costae towards the sinus in the pedicle valve and the fold in the brachial valve serve to distinguish it from other small members of the semireticular group.

In the Western Australian specimens the convergence of the costae is not so marked as in some of the Indian and Timor forms. Examination of the Timor specimens shows, however, that there is a large range of variation in the extent of the convergence.

Remarks.—As the internal features of this species are not known the generic placement is insecure. In external appearance the shells are similar to *Marginifera* Waagen, and knowledge of the internal structures is necessary before it can be said that they do not belong to that genus.

Dictyoclostus spiralis (Waagen).

Pl. ii, figs 8, 9.

1884.—*Productus spiralis* Waagen, p. 681, pl. lxvii, fig. 6; pl. lxviii, fig. 3; pl. lxix, figs. 1, 2, 3.

1916.—*Productus spiralis* Waagen, Broili, p. 11, pl. exvii, figs. 1-5.

1927.—*Productus spiralis* Waagen, Diener, p. 26.

1928.—*Productus spiralis* Waagen, Hamlet, p. 16.

Material.—Aus. Mus. F 36513, 36514, 36515, Wyndham Gap, North-West Division, Western Australia. Callytharra stage.

Diagnosis.—Shell large, regularly curved through 270°. Hinge-line equal to greatest width. Ears large and reflexed. Pedicle valve highly inflated with arched umbonal region, sides parallel and steep. Ornamentation reticulate on

posterior third of shell, eostate on anterior two-thirds, no development of folds on trail. Slight convergence of eostae in sinus. Ornamentation on ears partly reticulate, partly eostate, costae showing spiral arrangements. Row of spines along hinge-line and along line of separation of ears and flanks.

Brachial valve flatly concave with strong geniculation. Ornamentation reticulate on visceral disc, eostate on trail. Ears deeply excavated, smooth or with concentric wrinkles only. No spines. Cardinal process short, trifid. Well developed adductor muscle impressions. Muscle and brachial impressions of typical productid pattern.

Description.—Only pedicle valves are known from Western Australia. These have the following dimensions:—

Deserption.	1.	2.	3.
Length of hinge-line	88·2	....	63·0+
Height	45·6	58·1	48·9
Curvilinear length	134·0	112·0	99·4

The shell is large, as shown by the table, and curved in a regular spiral, there being no pronounced change in the rate of curvature throughout the period of shell growth. The umbo, though incurved, is blunt and scarcely overhanging the hinge-line. The hinge-line is straight and long, and forms the maximum breadth of the shell, about one quarter of this width being occupied by the ears alone. These are prominent features of the shell, they are strongly reflexed with a triangular outline. Their surface makes an obtuse angle with that of the flanks. A median sinus arises near the umbo and becomes deeper towards the anterior margin.

The ornamentation is reticulate on the posterior third of the shell, the rugae and costae being equally developed, thus giving an even pattern. On the trail the costae become more irregular, this irregularity being due to a change in disposition of the costae above and below the large spines which develop sporadically in this part of the shell. No grouping of the eostae into fasciculi is seen in this species. A row of strong spines occurs along the hinge-line and along the flanks at the line of separation of the ears. The ornamentation of the ears is one of the characteristic features of the species. No new eostae arise along the hinge-line after the shell ornamentation has ceased to be reticulate and those already formed become more widely separated as the shell grows and, following the curvature of the valve, show a spiral arrangement when viewed from the side.

Comparison with other species.—The spiral ornamentation of the ears is a distinctive character of this species, and differentiates it quite clearly from *Dictyoclostus callytharrensis*. The visceral cavity is much shallower in the latter species, not showing the arching in the umbonal region which is seen both in *D. spiralis* and in *D. callytharrensis* var. *wadei*. In both *D. callytharrensis* and its variation the costae on the trail are grouped into fasciculi, a condition not seen in *D. spiralis*.

For the distinction of *D. spiralis* from the Indian members of the *spiralis-subcostatus* reference should be made to Waagen (1884).

LINOPRODUCTUS Chao.

1927.—Chao, *Palaeont. sinica*, ser. B, V, fasc. 2, p. 128.

1928.—Chao, *ibid*, fasc. 3., p. 63.

1931.—Paeckelmann, pp. 75, 206.

Genotype.—*Productus cora* d'Orbigny, 1842, Voy. Amér, Mérid., vol. 3, Pal., p. 55, pl. v, figs. 8-10.

Diagnosis.—Thin-shelled Productids with convex pedicle valve; brachial valve flat or concave in viseeral portion, sometimes geniculated anteriorly. Hinge-line equal to or less than the greatest width. Both valves without cardinal area. Pedicle valve evenly convex or sinuate.

Surface ornamentation of fine radiating striae and indistinet concentric wrinkles; wrinkles more marked on the brachial valve. Scattered spines on striae present or absent.

Pedicle valve with marginal ridges weak and muscles not strongly impressed. Median septum in brachial valve. No brachial cones.

Remarks.—Chao has divided Linoproduetids with wavy undulations and pustulose spines into two groups, one characterised by *P. cancriniformis* (Tschernyschew), and the other by *P. villiersi* d'Orbigny. These groups are separated by the character of the brachial valve, regularly concave in *P. villiersi* and genienlate in *P. cancriniformis*.

***Linopproductus cora* (d'Orbigny).**

1842.—*Productus cora* d'Orbigny, p. 55, pl. v, figs. 8, 10.

1911.—*Productus cora* d'Orbigny, Diener, p. 19, pl. iii, figs. 3-13.

1914.—*Productus cora* d'Orbigny, Kozlowski, p. 48, pl. iv, fig. 19; pl. v, fig. 5; pl. vi, figs. 1-10; text-fig. 8.

1916.—*Productus cora* d'Orbigny, Broili, p. 19, pl. exv (1), figs. 14-15; pl. exvi (2), figs. 1-3.

1927.—*Productus cora* d'Orbigny, Chao, p. 132, pl. xiii, figs. 17-18; pl. xiv, figs. 1-4.

1927.—*Productus cora* d'Orbigny, Diener, p. 24.

For complete synonymy see Broili (1916) and Diener (1911).

Diagnosis.—Linoproduetids of variable size, transversely oval to elongated oval in shape, hinge-line equal to greatest width of shell.

Pedicle valve swollen, evenly convex in longitudinal profile, medially rounded or with broad sinus; tendency to spread and flatten in fan-like form anteriorly; flanks sloping steeply from viseeral portion. Shell arched over hinge-line, umbo incurved, slightly overhanging the hinge-line. Ears flat, their surfaces perpendicular to flanks of valve. Ornamentation of fine raised and rounded striae, subparallel or flexuous and irregular; increasing in number by interrealation of new striae between those pre-existing. Concentric folds on ears, not crossing viseeral disc. Row of spines along hinge margin, spines present or absent on rest of valve.

Description.—*Productus cora* was first described by d'Orbigny from South America, but the incompleteness of his description led to confusion in the interpretation of the species for many years. The examination of a large number of topotypes by Kozlowski in 1914 showed that there was a large variation within the species, and his description is here summarised. It varied in shape from transversely to longitudinally oval; the pedicle valve might be very swollen in the median region or only moderately so; the umbo was sometimes, but not always, strongly incurved; the pedicle valve was

sometimes impressed by a median sinus, sometimes regularly curved transversely; the striae varied in flexuosity and in the number of spines borne on the body of the valve. Each of these varied independently of the others, except possibly that the flexuosity of the striae was correlated with the presence of spines, one or more uniting, a spine arising at the point of union and the striae then disassociating.

Interiorly the dendritic adductor impressions of the pedicle valve are elongated and parallel to the median line while the diductor impressions are short, broad and longitudinally striated, arising at the lower edge of the adductors. The braehial valve has a raised median septum, adductors dendritic on each side of the septum, reniform impressions running laterally from the base of the adductors, following the lateral and antero-lateral margins, then returning to the point of origin. Cardinal process trilobed, median lobs raised above the two laterals. Marginal ridges arising at the base of the cardinal process and continuing along the hinge to the ears. A hollow separating the ears from the visceral disc, runs obliquely from the base of the cardinal process.

Remarks.—Diener in 1911, after examining a collection of Linoproduetid shells from the Fusulina Limestone of Kehsi Mansam suggested that *P. cora* d'Orbigny should be enlarged to include those forms previously assigned to the species *P. neffedievi* Verneuil, *P. corrugatus* McCoy, *P. prattenianus* Norwood and Pratten and *P. lineatus* Waagen. In this collection were forms which, while they could not be separated from the type specimens of these species, formed a continuous series with the specimens of undoubted *P. cora*. Diener's conclusions that *P. cora* included a wide variety of forms has since been strengthened by Kozlowski's work on the topotypes of *P. cora*. Kozlowski regards *P. prattenianus* and *P. lineatus* as members of the "cora" species group. He adds, too, *P. ovatus* Hall, but thinks that there is a definite, if unimportant, distinction between *P. cora* and *P. corrugatus* in that in the latter species the spines arise on any striae at its confluence with several others whereas in *P. cora* it is usual for the same stria to bear several spines at different places along its length.

These two authors have each had access to a large number of specimens and have, each independently of the other, found that *P. cora* is a very variable species and includes in itself *P. lineatus*, *P. prattenianus*, *P. neffedievi* and *P. ovatus*. The conclusion of such men, working with good material must be accepted, and even while these groups may be distinguished by varietal names, it must be remembered that they all belong to the one species group—*Productus cora* d'Orbigny.

Australian Distribution.—This species has been previously recorded and figured from Tillighary, N.S.W., by de Koninek. The specimens were, however, burnt in 1882. Other references to this species in Australian literature (Etheridge jun. 1872, Etheridge and Jack 1892, and Etheridge and Dun 1909) are not included in the synonymy of the species as in all the specimens figured the concentric markings are strong on the pedicle valve, a condition not shown in any of Kozlowski's or Diener's figures. These specimens have not been examined, and consequently no opinion is expressed on the validity of the identifications.

Productus cora has been recorded from Western Australia by Chapman and Glanert (1910, p. 87). It was recorded from the Kimberley District by

Chapman in 1924 (p. 36), but the specimen has since been re-examined by Miss Hosking, and re-identified as *Streptorhynchus luiliugui* (Hosking 1932, p. 45).

Linoprotodus cora var. foordi (Eth. fil).

Pl. iii, figs. 3-5.

1890.—*Productus tenuistriatus* de Verneuil, Foord, p. 151, pl. vii, figs. 4, 4a.

1903.—*P. tenuistriatus* de Verneuil, var. *foordi* Etheridge, jun., p. 19, pl. i, figs. 3-4; pl. iii, fig. 22.

1907.—*P. tenuistriatus* var. *foordi* Etheridge, jun., p. 30, pl. ix, figs. 4-6.

1910.—*P. tenuistriatus* var. *foordi* Eth. fil., Glauert, p. 87.

1931.—*P. tenuistriatus* var. *foordi* Eth. fil., Hosking, pp. 8, 22.

Specimens.—G.S.W.A. 1/4683, south bank of Wooramel River below Callytharra Spring, Callytharra Limestone.

G.S.W.A. 5708b., Fossil Cliff, Irwin River.

Aus. Mus. F 36247, 36251-36255 (incl.), Gascoyne River, near Winnemia, North-West Division. Byro Stage.

Aus. Mus. F 9027, Wyndham River, North-West Division. Byro Stage

Aus. Mus. F 36287, Gascoyne River, North-West Division. Byro Stage.

U.W.A. 10822, Fossil Cliff, Irwin River. Fossil Cliff horizon.

Diagnosis.—Linoprotodus with elongate oval outline, hinge-line equal to greatest width of shell.

Pedicle valve without median sinus. Visceral region very swollen, arching over hinge-line, umbo slightly overhanging hinge-line. Ears small and flat. Valve regularly curved in longitudinal profile. Striae fine, irregular, increasing by intercalation along a definite zone. Concentric wrinkles weak, not crossing visceral disc. Groups of spines at cardinal angles and one row at low angle to hinge-line.

Brachial valve concave, ornamentation as in *P. cora* d'Orbigny.

Description.—The pedicle valve has an elongated oval outline in the larger specimens. It is gibbous in the visceral region falling rapidly at the sides to small, flat ears, and truncated posteriorly by a small umbo overhanging the hinge-line. Anteriorly there is a decrease in the curvature so that the shell is elongated rather than globular. A row of spines along the hinge, at about 10° to the cardinal margin terminates in a group of from 4-6 spines on each ear. No spines occur on the rest of the shell. The longitudinal striae are fine (20-40 measured over a breadth of 20 mm. at a distance of 10 mm. from the umbo), and vary in irregularity. On some specimens they may run almost parallel for the length of the shell, but more usually two or more unite and re-divide later, having an irregular course. The striae increase by intercalation and this takes place in most specimens, at about the same stage of growth. The amount of increase, too, varies, one or two striae being intercalated between a pair of primaries. Folds on the ears are not seen on the majority of specimens and where they are present never cross the visceral part of the shell.

The brachial valve is concave, the ornamentation as in the pedicle valve, but crossed by concentric wrinkles. The valve is devoid of spines.

The sizes of the specimens (pedicle valves) are shown by the following table:—

—	1.	2.	3.	4.	5.	6.
Height	29·1+	22·8+	31·0+	23·7+	23·0+	14·1
Maximum width	29·4+	25·1+	27·0+	27·0+	24·0+	13·3
Length of hinge-line	22·9+	20·2+	19·8+	25·0	18·6+	13·3
Curvilinear length	50·0+	39·3+	56·0+	41·1+	35·5+	21·8

No specimens examined have both valves in position, it is thus impossible to estimate the thickness of the shell.

The width of the hinge-line as shown by these figures is less than the maximum width of the shell. The ears in these specimens are very fragile and readily break off; the only complete specimen is a small one (No. 6).

The internal structures are as described for the species *P. cora*, the muscles being inserted in definite fossae.

Comparison with other forms.—These specimens have been referred for many years to *Productus tenuistriatus* Verneuil, although distinguished as a variety. Etheridge (1903) separated them as a variety giving as his reasons the much coarser and more irregular ornamentation (in *P. tenuistriatus* there are 50-60 striae in 20 mm. at a distance of 20 mm. from the umbo). They differ from that species, too, in the width of the hinge-line, the arching of the pedicle valve and the regular anterior elongation, *P. tenuistriatus* being irregularly produced anteriorly. Etheridge has already said that this form belonged to the "cora" group (1907, p. 30). Specimens from Timor (Broili 1916, pl. exv., figs. 15-16; pl. exvi., figs. 1-3) probably belong to this variety of *P. cora*.

This variety is not distinct from *P. cora* d'Orbigny. It is a variety within that species as can be seen by a comparison of Kozłowski's figures (pl. vi., figs. 7a, b) and figures accompanying this paper, but a variety which has become stabilised in this area. The limits of variation are narrower than in those from South America. The shell shape is constant as is the convexity of the pedicle valve, it is not sinuated and does not carry spines on the main part of the shell. The varietal name is retained for these specimens until the complete range of *Productus cora* d'Orbigny is seen in this country.

Linopproductus cancriniformis (Tschermschew).

1889.—*P. cancriniformis* Tschermschew, p. 373, pl. vii, figs. 32, 33.

1897.—*P. cancriniformis* Tscher. Diener, vol. 1, Pt. III, p. 25, pl. vi, figs. 6a-b, 7a-d.

1897.—*P. cancriniformis* Tscher. Diener, vol. 1, Pt. IV, p. 31, pl. 1, figs. 7-10.

1907.—"P. undatus" Defrance, Eth. fil., p. 30.

1916.—*P. cancriniformis* Tscher., Broili, p. 13, pl. exvi, fig. 6.

1918.—"P. bellus" Eth. fil., p. 254, pl. xxxix, fig. 4-5; pl. xl, fig. 6.

1928.—*L. cancriniformis* (Tscher.), Chao, p. 65, pl. v, figs. 8-9.

1934.—*L. cancriniformis* (Tscher.), Prendergast, p. 14, pl. ii, figs. 7-12.

1936.—*L. cancriniformis* (Tscher.), Douglas, p. 30, pl. iv, fig. 3.

Material.—Aus. Mus. F 38453-38457, 9069, Minilya River, North-West Division. Wandagee Stage.

Aus. Mus. F 37580, $\frac{1}{4}$ mile west of shale outcrop. Northern bank. Same locality and horizon.

Aus. Mus. F 37576, $\frac{3}{4}$ mile east of shale outcrop. Northern bank. Same locality and horizon.

Aus. Mus. F 16729, 10749, Irwin River District Fossil Cliff horizon.

Aus. Mus. F 37565, $\frac{1}{4}$ mile east of fault, south bank of Minilya River, North-West Division. Wandagee Stage.

Diagnosis.—Linoprotuctids with non-sinuate pedicle valve, hinge-line equal to greatest width of shell, umbo overhanging hinge-line; ears distinct but not prominent. Shell ornamentation of fine striae, becoming swollen at regular intervals to give anteriorly-directed spines, quincuncially arranged. Row of spines along cardinal margin. Visceral disc erossed by concentric wrinkles; size and extent of wrinkles variable.

Brachial valve flat over visceral disc becoming strongly geniculated anteriorly. Short median septum. Ornamentation as on pedicle valve.

Internal features not known.

Description.—For description and discussion of this species see Prendergast, 1934, p. 14.

***Linoprotuctus cancriniformis* var. *lyoni* var. nov.**

Pl. iii, figs. 1-2.

Holotype.—Aus. Mus. F 36530, 10 chns. north-west of Gnarrea Pool near Winning Station, North-West Division. Lyons Stage.

Topotypes.—Aus. Mus. F 36533, 36535, 36537, 36538, 36540. Same locality and horizon.

Diagnosis.—Shell medium to large, semi-circular outline. Pedicle valve evenly convex, not swollen, without median sinus. Hinge-line straight, equals greatest width of shell. Umbo strong, not incurved, not overhanging hinge-line. Ears large, flat, not clearly differentiated from body of shell. Ornamentation as in *Linoprotuctus cancriniformis* Tsehern.

Brachial valve and internal structures of pedicle valve not known.

Description.	Dimensions.		
	36530.	36531.	36532.
Length of hinge-line	43.7	34.5	22.7
Height	32.6	28.0	21.5
Curvilinear length of pedicle valve	41.0	25.8	34.2

The pedicle valve has a semi-circular outline with the greatest width at the hinge-line. The longitudinal profile of the shell is a regular curve becoming geniculate near the front; transversely the curve is regular, without any median flattening. The ears are large with alar angles right angles, they are not distinct from the body of the shell. The shell surface is covered with fine radial striae (10-13 in 10 mm. measured at a distance of 20 mm. from the umbo) bearing swollen elongated spine-bases arranged in

quineunx. The striae increase in number by division of primaries. Concentric wrinkles are present on the ears but these rarely extend onto the body of the shell. A row of large erect spines is found along the cardinal margin.

Comparison with other species.—Only pedicle valves are known of this variety. These, however, are such a distinctive shape that it has been thought best to distinguish them temporarily as a variety of *Linoprotuctus cancriniformis* (Tsehern.). The ornamentation of the variety is similar to that of Tsehernsehew's species with the same fine radial striae and elongated pustules. They differ in the much less eonvex pedicle valve and in the semi-circular outline with the greatest width at the hinge-line.

The variety shows also a marked resemblance to *Productus asperulus* Waagen (1884 p. 693 pl. lxxix, figs. 3-6) in outline and type of ornamentation. The spines in that species are erect and not elongated pustules seen in *Linoprotuctus cancriniformis*.

Productus koninckianus de Vern. (Chao 1928, p. 63 pl. v, figs. 4-7) has also some features in common with these shells. It has, however, a much more inflated pedicle valve though several figures of smaller specimens (Chao 1928, pl. v, fig. 6) have a flat pedicle valve. The Western Australian specimens are always larger than these smaller shells and never have an inflated and incurved umbo. *Productus tumidus* Waagen (1834, p. 708, pl. lxxx, figs. 1-3) is also an inflated form and bears erect spines.

WAAGENOCONCHA Chao.

1927.—Chao, Y. T. *Palaeont. sinica*, Ser. B., V, fasc. 2, p. 85.

Diagnosis.—Thin-shelled productids with eonvex sinuate pedicle valve, brachial valve flat or concave. Surface marked by quincuncially arranged tubercular spines in the young and adult stages, becoming smaller and more closely packed together in old age.

Genotype.—*Productus humboldti* d'Orbigny, 1842, Voy. Amér. Mérid., Vol. 3, Pt. 4, p. 54, figs. 4-7.

Waagenoconcha imperfecta Prendergast.

Pl. iii, figs. 7-9.

1924.—“*Productus subquadratus*” Morris, Chapman, p. 36.

1934.—*Waagenoconcha imperfecta* Prendergast, p. 15, pl. iv, figs. 1-3.

Holotype.—U.W.A. 3044, Luiluigui Station, Kimberley Division, Liverynga Series.

Allotypes.—U.W.A. 2768, 2775, same locality and horizon.

Topotypes.—U.W.A. A 444, Luiluigui Homestead, Kimberley Division, Liverynga Series.

Other Material.—U.W.A. 20457, Limestone at base of Mt. Hardman, Kimberley Division, Liverynga Series.

U.W.A. 20454, north flank of Mt. Cedric, Kimberley Division, Liverynga Series.

Diagnosis.—Shell transversely oval in outline, hinge-line less than greatest width of shell. Ornamentation on both valves of coarsely spaced quincuncially arranged spine bases with fine forward projecting spines. Shell with well marked growth lines.

Pedicle valve evenly convex, sinuate, umbo prominent, produced beyond hinge-line.

Brachial valve flat to slightly concave with a shallow median fold. Margins not geniculate.

Description.—See Prendergast 1934, p. 15.

Remarks.—In the earlier specimens of this species examined it was noted that the specimens did not agree with the generic description since the spines were less crowded anteriorly. Specimens in a better state of preservation have since been obtained and these show that the inclusion of the species in the genus *Waagenoconcha* is quite justified. In these specimens the spines are crowded together on concentric wrinkles on the older parts of the shell. The absence of this feature on the earlier specimens was undoubtedly due to exfoliation of the outer layers of the shell leaving only coarser pustules more widely spaced.

When this species was originally described no copy of Broili's (1916) work on the Permian Brachiopoda of Timor was available and a new species was founded to contain specimens which belong to *Productus waageni* Rothpletz as figured by Broili. Comparison of the Western Australian specimens with Broili's figured specimens and with others from Timor (Basleo, Neoepantoeak, Toenion Eno, Tímor. B.M. B. 98397, 98985, 98648) leaves no doubt on this point. The Western Australian name is retained because it is doubtful if *P. waageni* Broili is identical with *P. waageni* Rothpletz.

Rothpletz's figures of *P. waageni* (1892, pl. x, fig. 19) show a small shell transversely oval in outline, ornamented with fine closely set spine bases. It shows no growth lines and has a very weak sinus in the pedicle valve. But Rothpletz compares his specimens with *P. humboldti* as figured by Waagen (1884, pl. lxxvi. figs 1-3), a rather surprising comparison as most of the specimens figured by Waagen have well-marked concentric ornamentation. Indeed Rothpletz's figures (pl. x, fig. 20) of *P. abichi* are more like *P. humboldti* Waagen. If *P. waageni* Rothpletz is identical with *P. waageni* Broili, then the absence of growth lines on Rothpletz's type is due to weathering or to individual variation. Without inspection of the type specimen of *P. waageni* Rothpletz, this species must be regarded as without growth lines.

Waagenoconcha vagans Reed.

Pl. iii, fig. 6.

1931.—*Waagenoconcha vagans* Reed, p. 9, pl. ii, fig. 2.

Material.—One brachial valve, U.W.A. 20459, north flank of Mt. Cedrie, Kimberley Division. Liverynga Series.

Diagnosis.—Shell trapezoidal to almost square in outline, hinge-line less than the greatest width of shell.

Pedicle valve sinuate, umbo swollen and overhanging hinge-line, ears flat. Ornamentation of small spine bases quincuncially arranged, pits occurring between spine bases.

Brachial valve flat with shallow median folds, margin geniculated.

Description.—This species is known in Western Australia only as an external cast of a brachial valve.

The shell is trapezoidal in outline, the greatest width at the anterior margin, this and the hinge-line being the parallel sides. The hinge-line is short and equal in length to half the maximum width of the shell. The flat visceral disc is divided medially by a shallow fold, the fold widening anteriorly. Laterally and anteriorly the margins of the valve are geniculated to form a fringe. The surface of the shell is ornamented by numerous hollows and spine bases quincuncially arranged (18 spine bases in 10 mm. 20 mm. from umbo), resembling the ornamentation of *W. imperfecta* mihi. Numerous growth lines cross the surface of the valve.

From its impression the umbo of the pediele valve seem to be swollen and overhanging the hinge-line.

The braehial valve has a length of 29 mm., with a maximum width of 38 mm.; the length of the hinge-line is 24 mm.

Remarks.—This species was first described by Reed from the middle Productus Limestone at Kumaranwali in the Warcha Valley of the Western Salt Range. It is characterised by the ornamentation in conjunction with the geniculation of the braehial valve.

TAENIOTHAERUS Whitehouse.

1928.—Whitehouse, *Rep. Aust. Ass. Adv. Sci.*, vol. xviii, pp. 281, 282.

Genotype.—*Productus subquadratus* Morris, 1845, in Strzelecki, Physical description of N.S.W. and Van Diemen's Land, p. 284.

Diagnosis.—Adult shell large, general outline subquadrate to elongate oval; pedicle valve evenly convex with median sinus; brachial valve slightly convex to flat with upturned margins. Pedicle valve sometimes with triangular eoneave area; delthyrium, where present, partially filled by triangular extension of cardinal margin of brachial valve.

Ornamentation of coarse elongated spine bases possibly giving rise to long spines; spine bases not continuous into eostae. Irregular eoneentric wrinkles or lamellae widely spaced over whole shell.

Muscle impressions as in *Aulosteges* and *Productus*. Brachial valve with median septum. Cardinal process large, varying angle of inclination to cardinal margin.

Remarks.—For description of this genus see Prendergast, *Proc. Roy. Soc. Tasmania*.*

Taeniothaerus subquadratus (Morris).

Pl. iv, figs. 1-6.

1845.—*Productus subquadratus* Morris in Strzelecki, p. 284.

1892.—*Productus subquadratus* Morris, Etheridge and Jack, p. 282, pl. xxxviii, figs. 7-10; pl. xl, fig. 5.

1907.—*P. subquadratus* Morris, Etheridge, jun., p. 21, pl. iii, figs. 6 and 7 (in the plate fig. 7 is labelled as fig. 1).

1907.—*P. subquadratus* Morris (?), Etheridge, jun., p. 30, pl. vii, figs. 2, 4; pl. viii, fig. 1.

1909.—*P. subquadratus* Morris, Etheridge and Dun, p. 300, pl. xli, figs. 1-5.

1910.—*P. subquadratus* Morris, Glauert, p. 87.

1914.—*Aulosteges baracooidensis* Eth. fil., Etheridge, jun., p. 33, pl. iv, figs. 11-13.

1931.—*P. subquadratus* Morris, Hosking, pp. 8, 22.

1933.—*P. subquadratus* Morris, Hosking, p. 36.

1933.—*Aulosteges cf. A. spinosus* Hosking, p. 36.

1935.—*P. subquadratus* Morris, Prendergast, p. 17, pl. iv, fig. 4.

Holotype.—B.M. 91171, Mt. Wellington and Mt. Dromedary, Tasmania.

Other Material.—U.W.A. 4768, 12396, 20450, 21247, Fossil Cliff, Irwin River, Fossil Cliff horizon.

U.W.A. 10931, two miles north of Ballythanna Hill, Wooramel River District. Byro Sandstone.

U.W.A. 20447, below Coolkilya Pool, Minilya River, North-West Division. Wandagee series.

G.S.W.A. 10930, Mt. Marmion Kimberley Division. Exact horizon not known.

G.S.W.A. 10929, locality and horizon not known.

G.S.W.A. 1/4655, locality and horizon not known.

* In January, 1941, Dr. Prendergast had completed a paper for the Royal Society of Tasmania on this subject, and was awaiting the illustrations, but the paper has not yet appeared.—E. deC. Clarke, 22/3/43.

Diagnosis.—Shell large, subquadrate to oval in outline. Greatest width near anterior margin. Pedicle valve strongly and evenly convex with median sinus, with or without cardinal area. Brachial valve slightly convex to concave with upturned margins.

Ornamentation essentially spinose. Spine bases elongated posteriorly. Concentric lamellae or wrinkles crossing shell surface.

Internal features as in *Productus* s.l. Cardinal process vertical to inclined almost to horizontality. Median septum in brachial valve.

Description.—This species has been described and discussed in Prendergast (*Proc. Roy. Soc. Tas.*)*, but some special features of the Western Australian shells are added here.

The pedicle valve is strongly convex with steep flanks and indented by a median sinus, which flattens out anteriorly so that the margin may be entire. The area is narrow in some specimens but may become wide. It is divided by a definite delthyrium which is partially filled by a triangular projection of the brachial valve. The adductor impressions are dendritic and placed high in the valve, the longitudinally striated adductors arise at the sides of the adductors and are produced laterally and anteriorly.

The brachial valve is flattish with a slightly convex region near the umbo; it is upturned at the margins. The cardinal process is strong and trilobed and varies in its inclination to the plane of the valve from being coplanar to almost perpendicular, the process in this case assuming a horizontal position. The median septum arises at the base of cardinal process and continues forward for about two-thirds of the length of the valve. The adductor muscle impressions are dendritic and enclosed in a heart-shaped elevation whose apex is at the base of the cardinal process. From the base of this elevation arise the brachial impressions, these running parallel to the hinge-line.

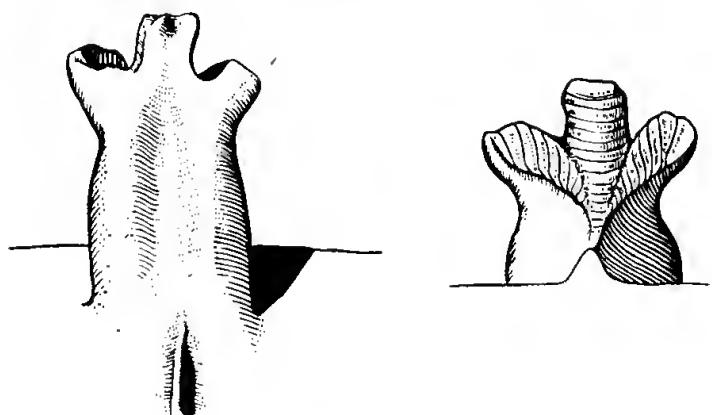


Figure 3.

Cardinal process of *Taeniothaerus subquadratus* (Morris). $\times 3$.

almost to the lateral borders then turning in a circular path and returning to their points of origin parallel to their outward path. At the base of the cardinal process arise two laterally directed ridges running parallel to the hinge-line but dying out before reaching the ears.

The ornamentation of the shell varies within rather wide limits. It is essentially spinose but the intensity of the spinosity varies from locality to locality. In the Irwin shells and those from the North-West Division the spines are very fine and closely set on concentric lamellae, in those from the Kimberley Division they are much thicker and fewer in number.

* See footnote p. 27.

Remarks.—From the Fossil Cliff Beds, Irwin River, are found shells which possess an elongated narrow area. Those specimens from the Byro sandstone of the Wooramel River have a distinct though not large area, while a specimen from the Kennedy sandstone (North-West Division) has been identified as *Aulosteges ingens* Hosking, although it differs from the Byro specimens only in the greater development of the area and the horizontality of the cardinal process. The stratigraphical relationships of these beds are given by Raggatt (1936) and Rudd and Dee (1932, MSS. unpublished).

N.W. Division and		
Wooramel River.		Irwin River.
Gascoyne Series		
5. Wandagee		
4. Kennedy		
3. Byro		
2. Wooramel		
1. Callytharra	=	Fossil Cliff Beds.

The specimens of these species may, then, be arranged in a time series, in which the area increases in size as the fossil-bearing rock is younger in age. The cardinal process also changes gradually through this series. In the typical *Productus* (e.g. *Dictyoclostus semireticulatus* (Martin)) the cardinal process is erect and in specimens with small areas this statement also holds for *Taeniothaerus subquadratus* (Morris). In *Aulosteges baracoodensis* Eth. fil., however, as in all *Aulosteges* the cardinal process has become bent through a right angle. This change, from vertical to horizontal, takes place gradually and keeps pace with the growth of the cardinal area. The suggestion is therefore made that *Taeniothaerus subquadratus* (Morris) is a transitional form connecting an unknown *Productus* with *Aulosteges baracoodensis* Eth. fil.

KROTOVIA Fredericks.

1928.—Fredericks, G., *Bull. Com. Geol. St. Petersb.*, 46, 1927, p. 790.

Genotype.—*P. spindulosus* J. Sowerby, 1814, *Min. Conch.*, Vol. 1, pl. lxviii, fig. 3.

Diagnosis.—Small thin-shelled producti. Pedicle valve convex, brachial valve concave to geniculate, closely following curve of pedicle valve. Ornamentation of fine spines in irregular quincuncial arrangement covering whole shell surface; spine bases elongated in anterior part of shell. With or without weak concentric wrinkles, median sinus only slightly developed or absent.

Internal structures unknown.

Comparison with other genera.—This genus differs from *Pustula* Thomas in the absence of marked concentric wrinkles and in the nature of the visceral cavity. In *Pustula* the brachial valve is flattish, forming a large visceral cavity, whereas in *Krotovia* the brachial valve follows the pedicle valve so closely that the visceral cavity is thin. Schuchert and Le Vene consider that this is not sufficient distinction as they say (1929, p. 72) of *Krotovia* "appears to equal *Pustula* Thomas." The shape of the body cavity is, however, a feature of diagnostic importance, and I have, therefore, adopted Frederick's genus.

Frederick's diagnosis of *Krotovia* (p. 790) states: "The shell has an oval configuration and a plain surface. The ornamentation consists of spines only," and in the Russian text (p. 779) "Sometimes irregular ribs and folds

develop which are connected with the spines." *Krotovia* then includes specimens with incipient plications thus overlapping with *Avonia* Thomas. Paeckelmann (1931, p. 77) has emphasised this fact, and distinguished *Avonia* s.str. and *Krotovia* as subgenera of *Avonia* Thomas, the forms to be separated by the presence (*Avonia*) or absence (*Krotovia*) of costae. The distinction is thus purely arbitrary, the two genera intergrading.

***Krotovia senticosa* (Hosking).**

1932.—*Pustula senticosa* Hosking, p. 47, pl. iii, figs. 2-3.

Syntypes.—G.S.W.A. 1/4970 (a), from Creek $\frac{1}{2}$ mile west of Callytharra Springs, Wooramel River. Callytharra Limestone

Diagnosis.—Thin-shelled form, outline semi-circular to subquadrate, hinge-line less than maximum breadth. Pedicle valve gently convex, non-sinuate, auriculate, umbo pointed and incurved. Brachial valve strongly eoncave; visceral cavity of *Productus typici* β type. Ornamentation on both valves of erect spines in irregular quincunx and fine concentric lamellae.

Internal features of pedicle valve unknown, brachial valve with short, broad cardinal process continuing into short median septum.

Description.—See Hosking, 1932, pp. 47-49.

Remarks.—The type specimens of this species have a convex pedicle valve with a concave brachial valve, the visceral cavity between the two being very thin. Also, as Miss Hosking says in her description (p. 48) "the lack of any marked concentric ornamentation is one of the chief features of the species." The specimens must, then, be referred to *Krotovia* rather than to *Pustula*.

***Krotovia micracantha* (Hosking).**

1932.—*Pustula micracantha* Hosking, p. 49, pl. iv, figs. 4a, b.

Syntypes.—G.S.W.A. 1/4970 (b), from Creek $\frac{1}{2}$ mile west of Callytharra Spring, Wooramel River. Callytharra Limestone.

Diagnosis.—Small, thin-shelled form. Shell outline semi-circular to subquadrate, hinge-line slightly less than greatest shell breadth. Pedicle valve geniculate, non-sinuate; umbo small, not overhanging hinge-line. Brachial valve deeply concave and geniculate, closely following contour of pedicle valve; visceral cavity of *Productus typici* β type. Ornamentation on pedicle valve of recumbent spines in irregular quincunx with concentric folds posteriorly and on ears.

Short median septum in brachial valve. Other internal features not known.

Description.—See Hosking, 1932, pp. 49-50.

Remarks.—From an examination of the type specimens there can be no doubt that this species should be referred to *Krotovia*. The visceral cavity is thin, the concentric wrinkles are not pronounced and the nearest British form is *P. spinulosus* J. Sow., the genotype of *Krotovia*.

***Krotovia spinulosa* (J. Sowerby).**

Pl. iv, figs. 11-13.

1814.—*Productus spinulosus* J. Sowerby, p. 155, pl. lxviii, fig. 3.

1860.—*Productus spinulosus* J. Sowerby, Davidson, p. 182, pl. ii, figs. 23, 24.

1861.—*Productus spinulosus* J. Sowerby, Davidson, vol. ii, part 5, No. 4, p. 175, pl. xxxiv, figs. 18-21.

1914.—*Pustula spinulosa* J. Sowerby, Thomas, p. 314, pl. xviii, figs. 7-9; pl. xix, figs. 7, 8.

1930.—*Krotovia spinulosa* (Martin), Muir-Wood, p. 106. (There is no *Productus spinulosus* Martin—this is a mistake in author of species).

Holotype.—Present location unknown, listed as Royal Scottish Museum, Edinburgh, Fleming Collection. Carboniferous Limestone, West Lothian, Linlithgowshire.

Material.—Aus. Mus. F 38442, 38443, 38446, Wandagee Station, Minilya River, North-West Division. Wandagee Stage.

Aus. Mus. F 37563, 37564, 37578, 37582, bank of Minilya River, North-West Division. Wandagee Stage.

Aus. Mus. F 37725.

Aus. Mus. F 37579, $\frac{1}{4}$ m. west of shale outcrop, northern bank of Minilya River, North-West Division. Wandagee Stage.

Diagnosis.—Shell small. Outline oval, hinge-line less than maximum width. Pedicle valve convex, non-sinuate, umbo small, pointed and incurved, overhanging hinge-line; ears small and flat. Brachial valve evenly concave. Visceral cavity of *Productus typici* β type. Ornamentation on both valves of fine oblique spines, closely spaced, with quincuncial arrangement. Development of incipient costae below spines near anterior margin.

Internal features not known.

Description.	Type.	Dimensions.	
		F 38443	F 38446
Height		16.2	16.5
Length of hinge line		10.5+	12.5
Maximum width		11.7+	17.3
Curvilinear length of pedicle valve		29.4	27.4

The shells of this species, as may be seen from the table, are small. Usually transversely oval, they have a straight hinge-line shorter in length than the maximum width of the shell.

The pedicle valve is evenly convex, without a median sinus. The shell has its maximum convexity behind the umbo; from this point the sides drop steeply to flat ears; anteriorly the slope is more gradual. The alar angles are obtuse. The umbo is small, pointed and overhanging the hinge-line. The surface of the valve is ornamented by small closely-set spine bases (10-12 in 10 mm. at a distance of 10 mm. from the umbo). These give rise to slender oblique spines on the body of the shell; they have not been observed on the ears, but a row of erect spines separates the ears from the body of the shell. On the anterior and lateral slopes small ripples (? incipient plications) are seen anterior to the spine bases.

The brachial valve is regularly concave with the maximum concavity just beneath the umbo. The ears are flat and in contact with those of the pedicle valve. The ornamentation is the same as that seen on the pedicle valve, but no spines are preserved on the brachial valves. A few growth lines cross the shell.

Comparison with other species.—*Productus opuntia* Waagen resembles this species in many particulars. Both have the same outline, but may be distinguished by the location of the maximum width which in *P. opuntia* is the length of the hinge-line. The spine bases of *P. opuntia* are not so crowded as those of *P. spinulosus* and generally are more robust, having a distinct anterior prolongation and are also more nodular.

Girty (1908, p. 264) compares his species *Productus signatus* with *P. opuntia*. The figures are not clear, but give an impression of an ornamentation of *Cancerinella* rather than of *Krotovia* or *Pustula*. The spine bases are heavy and elongated, and Girty himself says that on some of the casts irregular lirae can be seen between the spine bases. The species is distinct from *K. spinulosa*.

The characters distinguishing the other species of this genus, *Krotovia micracantha* and *Krotovia senticosa*, from this species are dealt with in the description of those species.

AULOSTEGES Helmersen.

1847.—Helmersen. Leonhard & Brönn's Jahrbuch für Mineralogie p. 331, text-figure.

Genotype.—*Aulosteges variabilis* Helmersen = *Orthis wangenheimi* (Verneuil). Helmersen 1847, Leonhard and Brönn's Jahrbuch für Mineralogie, p. 331, with text-figure.

Diagnosis.—Medium to large shells, ovoid to quadrangular or triangular in outline. Coneavo-convex or platy-convex dorso-ventrally. Ornamentation essentially spinose with development of radial lirae or concentric wrinkles.

Pedicle valve convex with well-developed area and pseudo-deltidium. Umbo pointed, possibly deformed or with eicatrix of attachment. Edentulous. Shell with median sinus.

Brachial valve flat or concave, without area or area narrow and linear. Cardinal margin produced into triangular extension medially. Median septum separating dendritic muscle impressions. Pattern of brachial impressions productiform. Cardinal process large, inclined or horizontal.

Description.—The shells of this genus are usually massive although there is a great variation within the genus. They vary in shape from oval to quadrangular and triangular, the hinge-line being less than the greatest width of the shell. Neither the pedicle nor the brachial valve is produced into distinct ears.

The pedicle valve is regularly convex or geniculate. Transversely it is depressed by a median sinus which commences some distance behind the umbo, is strongest in the centre of the shell and flattens out towards the anterior margin. The area is triangular and usually well-developed, it is marked by vertical or longitudinal striations and may be flat or concave; the concavity may not be regular and a sudden change in curvature gives the recurved area seen in *A. spinosus*, Hosking. A narrow pseudo-deltidium, triangular or parallel-sided, divides the area. In some specimens, for instance *Aulosteges wangenheimi* (Verneuil), small spines are present on the pseudo-deltidium. These are not seen in all other species, but their occasional occurrence suggests that their absence is secondary, due to removal. The umbo is sharp and pointed, and usually erect. Where, however, the umbo has been deformed by attachment, it may be twisted to one side or produced across the area (see, for example, *Aulosteges baracooidensis* Eth. fil., 1914, pl. iv, fig. 13). The surface of the valve is ornamented by spines, erect and/or adherent, and may be concentrically wrinkled on the visceral disc. Radial lirae are seen in some of the species, e.g., *A. wolfcampensis* King and *A. medlicottianus* Waagen, while stronger radial markings ornament the trail in *A. tibeticus* Diener.

The braehial valve of the genotype *A. wangenheimi* (Verneuil) is slightly convex over the visceral disc, becoming concave with geniculated margins. This valve has an opereuliform character throughout this genus, serving as a flattish or slightly concave lid for the viseeral cavity. The ornamentation is as in the pediele valve.

A description of the internal features of a brachial valve of *A. wangenheimi* (B.M. BB 3279) will illustrate the characteristic features of the valve.

The cardinal process is large and trilobate, it is inserted perpendicular to the hinge-line so that it extends horizontally, not vertically as in the *Productids*. The roots of the cardinal process extend posteriorly, and some part of them now lies behind the hinge-line. This is protected externally by a triangular extension of the brachial valve which fills the delthyrium of the pediele valve. This structure of the cardinal proeess is characteristic of the genus.

At its base the cardinal process is continued into two thickened ridges which run parallel to the hinge-line, leaving, posterior to them, a rectangular platform of which the surface of the valve forms the back and the thickened ridge the floor. The development of these ridges varies within the one species even under the same environmental eonditions; one of the specimens examined (B.M. BB 3278) had them enormously thickened (see Figure 4), while in another they were but feebly developed with little lateral expansion. In the thickened specimen two ridges, directed towards the centre of the shell, arise at the base of the cardinal process and unite in the middle line to continue forward as the median septum. These two ridges and the lobes of the eardinal process form the edges of a diamond-shaped depression which separates the cardinal process from the median septum. With less-developed ridges the anterior sides of the depression become obscured.

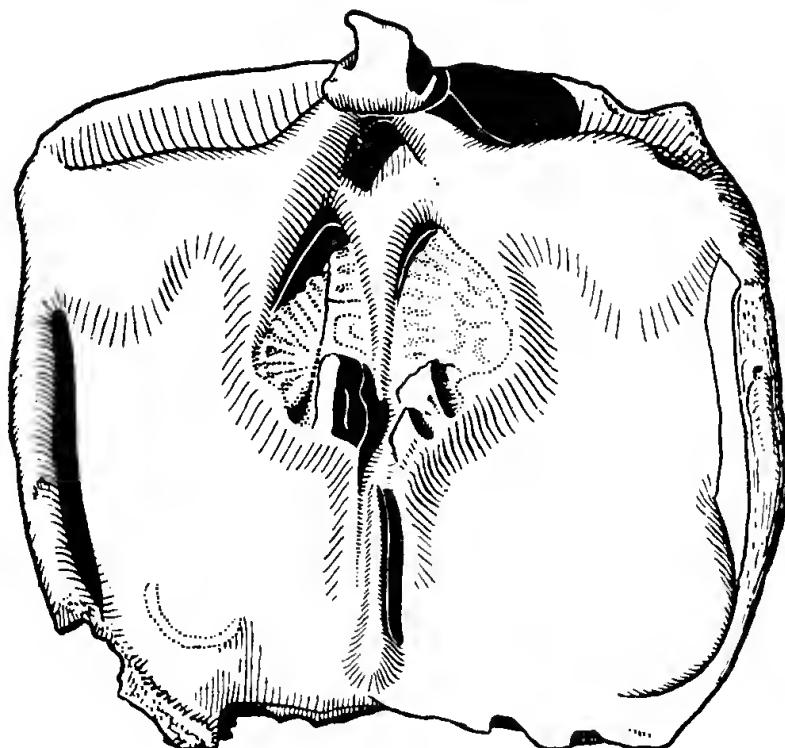


Figure 4.

Interior of Brachial Valve of *Aulosteges wangenheimi* (Verneuil). Permian.
Mt. Grebeni, near Orenburg, Russia. B.M. BB 3279 ($\times 3$).

The dendritic muscle impressions are situated in sub-triangular depressions on each side of the median septum. At the base of each, the brachial impression arises, runs parallel to the hinge-line almost to the lateral margin, then turns anteriorly to form an open loop. On no specimen have the impressions continued to the median septum. In the area circumscripted by the brachial impressions the inner shell surface is smooth and shiny, elsewhere it is finely pitted.

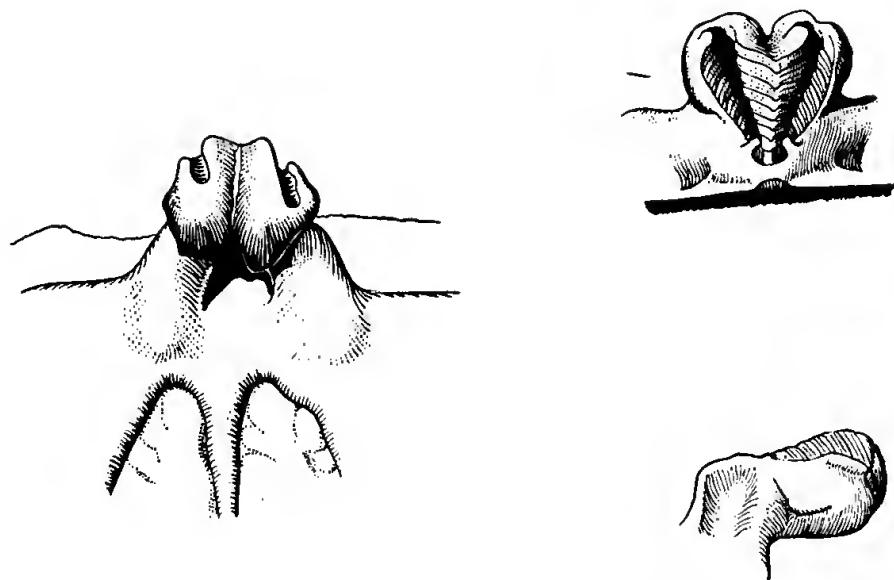


Figure 5.

Cardinal Process of *Aulosteges wangenheimi* (Verneuil). Permian. Mt. Grebeni, near Orenburg, Russia. B.M. BB 3278. (a) vertical, (b) lateral (c) horizontal ($\times 3$).

Comparison with other genera.—The genus *Aulosteges* is distinct from members of the *Strophalosiinae* in the possession of a high reclinéd area, poor articulation, a cardinal process orientated perpendicular to the commissural plane of the valves, the triangular extension of the cardinal margin of the brachial valve and the dendritic adductor impressions in the brachial valve.

The high area of *Aulosteges* and the horizontal inclination of the cardinal process serve as distinguishing features from the *Productus spinosi* group.

In view of the prevailing opinion of Russian palaeontologists that *Aulosteges* is a synonym of *Strophalosia*, the differences between the two genera will be considered more fully. Netschajew (1911, p. 144) states that the only significant feature distinguishing the two is the presence of deltoidal spines in *Aulosteges*. Such a statement completely ignores the differences in the internal structure of the brachial valve. It must be admitted, however, that the internal features of the Russian species *Strophalosia horrescens*, *S. fragilis* and *S. gigas* are very similar to those of *Aulosteges*. The muscle impressions are dendritic, the cardinal process inclined towards the horizontal and the pattern of the brachial impressions productoid. It is here that the error lies, for those species mentioned above do not belong to the genus *Strophalosia*, they are *Aulosteges*.

Licharew (1937, p. 128), while stressing the synonymy of *Aulosteges* and *Strophalosia*, recognised that the Russian "*Strophalosia*" did not come within the accepted conception of that genus. He compromised by suggesting

that the *S. horrescens* group should be distinguished as *Aulosteges*, a sub-genus of *Strophalosia*. But why a sub-genus? *Strophalosia* is distinguished by non-dendritic muscle impressions, a smallish cardinal process, a perlined area of moderate height in the pedicle valve and well-developed dentition. What features, therefore, have *Aulosteges* and *Strophalosia* in common that would induce us to consider one as a sub-division of the other? The possession of a concavo-convex shell with an area on the pedicle valve and usually a spinose ornamentation is surely insufficient evidence for this grouping when so many points of difference are considered.

Fredericks has a more positive reason for distinguishing between the two genera. He says (1931, p. 209) that both genera are characterised by the presence of an apical apparatus representing a reduced spondylium. The apical plates have become delthyrial ridges and the secondary septum a median ridge. These elements, Fredericks says, retain their connection at the apex of the umbo. He publishes no diagrams in support of this hypothesis, which rests, therefore, solely on his interpretation of these structures—structures which would be preserved in only those specimens where no deformation of the umbo had occurred. The presence of such a structure would not do more than suggest a similar origin for both genera, a view which has not been disputed, and if other points of difference are present, would not preclude the maintenance of each as a separate genus.

Subgenera.—Two subgenera of *Aulosteges* have been proposed:

Wyatkina Fredericks.

Strophalosiina Licharew.

These subgenera agree with *Aulosteges* in essentials, but differ in minor details.

Wyatkina Fredericks (1931, p. 210 footnote) with subgenus-holotype *Aulosteges gigas* Netschajew includes:—

"*Strophalosia*-like forms, yet with primitive apical apparatus devoid of delthyrial ridges and euseptoid. Ornamentation consisting of thin spines. Muscle impressions of the ventral valve and structure of the dorsal valve as in *Strophalosia*." (The *Strophalosia* of this paragraph refers to the Russian forms, i.e., *Aulosteges*.)

Licharew suggests (1937, p. 128) that the delthyrial ridges are probably only present when the deposition of shell substance has been excessive and these ridges would be the outward manifestation of teeth. This explanation seems quite plausible. As few *Aulosteges* possess either teeth or delthyrial ridges, Fredericks's subgenus would include nearly all the members of the genus. Further observations are necessary before any conclusion can be accepted with certainty.

Strophalosiina Licharew (1935, p. 369) with subgenus-holotype *Aulosteges tibeticus* Diener is distinguished from other members of *Aulosteges* by its geniculate pedicle valve and peculiar ornamentation. Anterior to the geniculation the surface of the shell is covered with radial plications while on the viseral disc the plications are replaced by irregular concentric wrinkles and radially arranged pustules.

These subgenera, *Wyatkina* and *Strophalosiina* are closely related. Indeed, from a study of the literature they seem identical, since according to Hamlet, *A. tibeticus* == *A. medlicottianus*, while Renz says that *A. gigas* ==

A. medlicottianus; therefore, since those things which are equal to the same thing are equal to one another:—

A. tibeticus = *A. gigas*,
therefore *Wyatkina* = *Strophalosiina*.

If the premises are true *Strophalosiina* is a synonym of *Wyatkina*. The author has not been able to see the original description and figures of *A. gigas*, so cannot discuss its affinities with *A. tibeticus*. The diagnostic feature of *A. tibeticus* is the ornamentation, and later writers on *A. gigas* do not describe that shell as radially plicate.

Until further information is available, *Strophalosiina* and *Wyatkina* are accepted as subgenera of *Aulosteges*.

***Aulosteges spinosus* Hosking.**

Pl. iv, figs. 7-10.

1931.—*Aulosteges spinosus* Hosking, p. 17, pl. iii., figs. 7a-d.

1933.—*Aulosteges spinosus* Hosking, p. 37.

Material.—Ans. Mus. F 38444, 37710, Wandagee Station, Minilya River, North-West Division. Wandagee Stage.

Diagnosis.—Shell small to medium in size, subquadrangular, wider than long. Surface of both valves with small perforated tubercles bearing small spines.

Pedicle valve convex, not swollen, faint median sinus. Umbo high, not overturned. Area broad, slightly concave and recurved to cardinal margin, pseudo-deltidium narrow, highly arched.

Braçhial valve flat, triangular extension of cardinal margin large.

Internal features unknown.

Description.—For complete description of this species reference should be made to Hosking (1931, p. 17 et seq.).

Two rather dissimilar species from the North-West Division are here referred to this species.

Dimensions.

		Type :	38444.	37710.
Length	....	18·8	45·1 +	20
Breadth	....	19·7 +	43·0 +	22
Length of hinge-line	....	14·5	21·3 +	15
Thickness	....	—	7·4	—

F 38444 is a complete specimen with both valves. The umbo is distorted by a cicatrix of attachment and twisted slightly to the left. The area is high and very worn so that no growth lines or transverse striations are preserved. It has the same recurving to the cardinal margin as noted by Hosking in the description of the holotype. The pseudo-deltidium is narrow and parallel-sided; it has twisted, with the twisting of the umbo, to the left. An indentation of the valve, as the beginnings of a median sinus, occurs near the anterior margin. The ornamentation of the pedicle valve is of fine forward-projecting spine bases.

The brachial valve is flat and is without an upturned margin. The median septum crosses two-thirds of the length of the shell. The surface of the valve is roughened by weathering, but numerous pits indicate the former presence of spines.

A much larger specimen, F 37710, is a pedicle valve with a high undistorted area. The valve has the same recurved margin and ornamentation as seen in the type. The median sinus is well-developed anteriorly, but is faint on the visceral portion of the shell. The area is wide and longitudinally striate; the pseudo-deltidium is narrow, parallel-sided and bears nodular perforated tubercles; it is short, continuing for only half the width of the area so that a large open space occupies the centre of the cardinal margin (filled, when the brachial valve is in position, by the triangular extension of the cardinal margin). This specimen differs from the type in size and in the possession of deltoidal spines. Although no intermediate forms are known it is impossible to separate the specimen on those grounds alone. The deltoidal spines are rarely present in species of *Aulosteges* and their absence may be due to removal by weathering rather than to a difference in development.

Remarks.—The distinctive feature of this species is the sharp recurring of the area, a feature not seen in other species of the genus.

The appearance of a larger shell with the same characteristics as those described for *Aulosteges spinosus* nullifies the suggestion of Hosking (1931, p. 19) that this species was possibly only the young form of *Aulosteges ingens* Hosking.

STROPHALOSIA King 1844.

1844.—King, *Ann. Mag. Nat. Hist.*, XIV, p. 313.

Genotype.—*Orthis excavata* Geinitz, Ueber einige Petrefacte des Zechsteins und Muschelkalks. *N. Jb. Min. Geol. Paläont.* 1842, p. 578 Taf. x figs. 12, 13.

Diagnosis.—Small to medium-sized shells. Concave to platy-convex dorso-ventrally with well-developed areas on both valves. Umbo distorted by cicatrix of attachment. Ornamentation essentially lamellar, lamellae usually interrupted by spines on pedicle valve; spines rarely present on brachial valve.

Pedicle valve with teeth fitting into sockets of brachial valve. Brachial valve with median septum, non-dendritic muscular impressions and pronounced brachial impressions. Trifid cardinal process well-developed.

Description.—The members of the genus *Strophalosia* are never large shells; they vary in shape from longitudinally to transversely oval, with the hinge-line equal to or slightly less than the greatest width of the shell. The pedicle valve is usually evenly convex, rarely geniculate. The brachial valve is, however, usually geniculate, being flat or concave in the visceral portion with upturned lateral and anterior margins. Both valves possess a distinct area, that of the pedicle valve being the larger. There is no open delthyrium, a pseudo-deltidium being always present.

Strophalosia has been described as a spinose Productid with an area. This description is, however, a little restricted, as all species of *Strophalosia*, for example *Strophalosia kimberleyensis* mihi, do not possess spines. The characteristic of the ornamentation is rather its lamellar structure. The lamellae are usually distinct, their outer surfaces and edges forming the external shell surface. This distinctness of the lamellae indicates that in the

members of the genus shell formation was limited, probably by physical conditions, to certain times of the year, the periods of shell deposition being separated by intervals of quiescence during which no shell was deposited. That this response to physical conditions is a generic characteristic rather than due to abnormal physical conditions may be inferred from a study of forms living under the same physical conditions in which the lamellar structure is not seen.

Spines are often present; these may be recumbent or erect, many or few; they may be of two series or uniform in size, and are usually present on the pedicle valve, though but rarely found on the brachial valve.

Internally, the structures of the brachial valve are characteristic of the genus, and the changes within the genus are largely reflected in the structure of this valve. A median septum is always present, varying in length from one-third to two-thirds of the length of the visceral portion of the valve. It separates the non-dendritic adductor muscle impressions which vary in position but show no relation in their variation to the length of the median septum. The adductor impressions are usually divided into anterior and posterior adductors, but sometimes (e.g. *Branxtonia*) no such division is seen.

The brachial impressions arise at the side of the adductor muscle scars and vary in position with the position of the muscles. Where the muscles are medial or lower in the valve, that is, towards the anterior margin, the brachial impressions run almost parallel to the hinge-line and curve abruptly to the median septum, the condition seen in the *Productus* group. Where the adductors are situated higher in the valve the brachial impressions are found near the cardinal and lateral margins and approximately parallel to them.

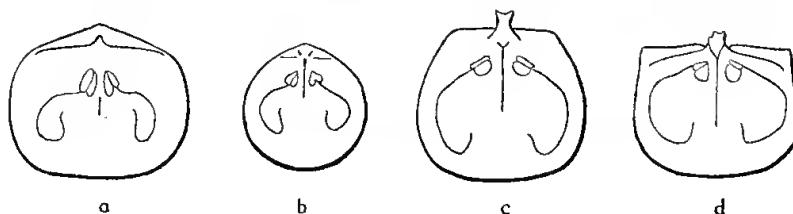


Figure 6.

Internal Features of Brachial Valves—to illustrate the alteration in position of the Brachial Impressions. (a) *Productus latirostratus*, (b) *Strophalosia lamellosa* var. *humbletonensis*, (c) *Str. jukesi*, (d) *Str. kimberleyensis*. (a), (b) and (e) after Davidson ($\times \frac{1}{2}$).

The cardinal process, while it varies in minor details, retains throughout the genus, its typical trifid character. The process is always a compact one, the three parts being on the same horizontal level, in contrast with some Productids, e.g., *Taeniothaerus subquadratus*, where the central lobe is raised above the lateral lobes. The structures at the base of the process vary; this variation will be discussed later (p. 39).

In the pedicle valve the adductor impressions are non-dendritic, central and varying in their position in the valve as do those of the brachial valve. The adductor impressions surround those of the adductor muscles and are longitudinally striate.

In life the shells of this genus were probably orientated with the heavier pedicle valve resting on the substratum, the curvature of this valve and the upturned margins of the brachial valve keeping the open edges of the shell above the level of disturbed water. The umbonal cicatrix shows that the

shell was attached at some period, but it is not known for what length of its life the shell maintained this position. If the shell was fixed only by cementation the period of attachment was probably short as no specimens are known with the shell in this position nor are they usually broken across the umbonal region as one might expect. If, however, a process of the mantle aided cementation during life the shell would fall after the death of its inhabitant. There are no indications to show that such a process or processes existed, and one must conclude, in the absence of evidence to the contrary, that the *Strophalosias* were attached only during the earlier stages of growth.

Remarks.—The large variation within the genus *Strophalosia* is undoubtedly due to the rate of adaptation in the different species to the sedentary mode of life.

In *Strophalosia lamellosa* var. *humbletonensis* the shell shows a clear resemblance to *Productus* in the arrangement of the musculature and brachial impressions. The adductor muscle impressions are central and the brachial impressions have a distinctly Productid aspect (see fig. 6, p. 38).

If a form such as this assumed a sedentary mode of life with the point of attachment beneath the umbo, it is obvious that the structure is mechanically unsound, as the muscles in working, will be pulling against the point of attachment. To overcome this instability the muscles would tend to move backwards in the shell until they came to rest over the scar of attachment. This posteriorly directed movement of the muscles would push all those structures posterior to them backwards, and these would thus tend to atrophy or be replaced by the originally more anterior elements. The backward movement of the muscles necessarily causes an alteration in the position of the brachial impressions, as already seen (see p. 38).

In *Strophalosia* species with anteriorly placed muscle impressions, two oblique ridges arise, one on each side of the median septum, beneath the umbo and continue antero-laterally at an angle of about 45° to the hinge-line. As the muscles move posteriorly these ridges become displaced and gradually become the horizontal cardinal ridges as seen in *Str. kimberleyensis* mihi. They also impinge on the hinge-line so that the base of the cardinal process has different appearances according to the stage of movement of the muscles.

Licharew (1937, p. 127) states that the extreme condition of this movement is that shown by the Russian specimens in which the ridges have been pushed beyond the hinge-line, taking with them the sockets. The species to which Licharew refers, *Str. fragilis* and *Str. horrescens*, have dentritic muscle impressions and must be placed as members of the genus *Aulosteges*. Moreover, examination of the cardinal process of *Str. horrescens* shows that it has the typical trilobate structures and is not bifid, as might be expected if its mode of formation was as stated by Licharew. The backward movement of the ridges does change the form of the base of the cardinal process, but I have seen no specimen in which they replace it. The poor condition of the specimens of *Str. clarkei* figured by Etheridge (1880) led Licharew to think that this series of changes took place within that species. *Str. clarkei* does represent an advanced stage, in that the muscle impressions are high and the ridges have come to assume a position almost parallel to the hinge-line but the cardinal process has not been affected and the dental sockets are deep.

Comparison with other genera.—*Strophalosia* may be distinguished from both *Aulosteges* and *Productus* sensu lato by many features. In general,

Strophalosia has a well-developed area on each valve, *Aulosteges* on the pedicle valve only, while *Productus* is without a true cardinal area. This distinction does not, of course, hold for all the *Productus* subgenera, in some of which, a cardinal area is developed. The non-dendritic adductor muscle impressions serve, however, to distinguish *Strophalosia* from both *Aulosteges* and *Productus* as in these genera the adductors are always dendritic. The posterior movement of the muscles and consequent change in pattern of the brachial impressions is also a typical Strophalosoid feature.

Subgenera.—In recent years there has been much work done on the species of this genus, and it has now been subdivided into five subgenera:—

ETHERIDGINA Oehlert (= **LEPTALOSIA** Dunbar & Coudra)
STROPHALOSIINA Licharew
STROPHALOSIELLA Licharew
WYNDHAMIA Booker
HETERALOSIA King

and with *Aulosteges* as a possible sixth or alternatively as a synonym. The relation of *Aulosteges* and *Strophalosia* has already been discussed (p. 34).

Etheridgina includes those *Strophalosias* in which the shell is attached throughout the life of the animal, both by embracing spines and directly by the pedicle valve. A small cardinal area and teeth are sometimes, though not always present. *Leptalosia*, to include those forms possessing an area and teeth, cemented directly by the pedicle valve, was founded by Dunbar and Coudra in 1932. Examination of the type specimens of *Etheridgina complectens* (Eth. fil.), the genotype of *Etheridgina* shows, however, that some of these specimens possess the hinge structures thought to be typical of *Leptalosia*. *Leptalosia* becomes, therefore, a synonym of *Etheridgina*. This question is more fully discussed under *Etheridgina*.

The genotype of *Strophalosiina* Licharew is *Aulosteges tibetius* Diener. This species undoubtedly belongs to *Aulosteges* and is, under this system of classification, regarded as a subgenus of *Aulosteges*.

Strophalosiella Licharew with genotype *Strophalosiella coraeformis* Licharew is a very doubtful genus. The specimen figured and described by Licharew is a plicate form ("a *Strophalosia* with Linoproductid ornamentation") with well-developed areas on both valves. In the absence of any knowledge of the internal structure it seems impossible to assign this specimen to the genus *Strophalosia*. Until this knowledge is available it would seem better to maintain it as an independent genus of unknown affinities.

Wyndhamia was founded by Booker in 1929 for the reception of a group of Strophalosoid forms with adductor muscles undifferentiated into anterior and posterior elements and without evidence of a period of attachment. The position of the muscle scars (placed posteriorly in the valve) would indicate that the species of this subgenus (*W. valida* Booker and *W. dalwoodensis* Booker) had attached ancestors, and had retained some of the ancestral characteristics, although they themselves had ceased to be attached. The assumption of these distinctive features, undifferentiated adductor muscle scars and absence of a cicatrix, is sufficient to characterise the subgenus. The type species of the subgenus is *Wyndhamia dalwoodensis* Booker from Permian beds of Branxton, New South Wales.

In the same paper (1929, p. 30) Booker also proposed a new subgenus *Branxtonia* of *Productus*. The author has not been able to see the specimens of the genotype, *Branxtonia typica* Booker, but from Booker's own figures and similar specimens from Western Australia, suspects that the specimens

are Strophalosias. They show the same structure and arrangement of the muscle scars in the brachial valve, and the impression of dental callosities may be seen on the casts. The specimens do not show an area, but until specimens with some shell preserved are seen it is impossible to say that its absence is not due to thickening of the hinge-line behind the area. If no area is present then *Branntonia* must be regarded as an attached form or of a line of attached Productids with consequent muscle movement as in *Strophalosia*.

Heteralosia King (1938, p. 278) with genotype *H. slocomi* King is distinguished from *Strophalosia* s.s. by the possession of a non-spinose brachial valve. It seems doubtful whether a division of the *Strophalosias* based on the ornamentation of one or the other valve is of great advantage, and although of the species here described *S. etheridgei* and *S. gerardi* (?) would be placed in *Heteralosia* I have left them in *Strophalosia* s.l. If King's division is accepted, a new genus, without spines on either valve, must be proposed to include *S. clarkei* and *S. kimberleyensis*.

Strophalosia cf. Strophalosia beecheri Rowley.

Pl. v, figs. 1-3.

1893.—*Strophalosia beecheri* Rowley, p. 308, pl. 14, figs. 18-19.

1908.—*Strophalosia beecheri* Rowley, p. 76, pl. 17, figs. 24-25.

1914.—*Strophalosia beecheri* Rowley, Weller, p. 146, pl. xix, figs. 37-38.

Material.—U.W.A. 20449, one specimen—conjoined valve; Waltharrie Pools, Woormel River District; Callytharra Limestone.

Diagnosis.—Shell small, almost circular in outline, hinge-line slightly less than greatest width of shell. Surface ornamentation of erect spines of approximate quinemicial arrangement and fine growth lines.

Pedicle valve convex, asymmetric without sinus though flattened medially and sloping steeply anteriorly and laterally. Cincatrix large, placed on one side of umbo. Area as long as hinge-line, flat and triangular. Pseudodeltidium triangular. Teeth short and diverging.

Brachial valve concave, area distinct, almost as large as that of pedicle valve, pseudo-chilidium large and triangular.

Internal features not known.

Description: *Dimensions of Specimen.*

Height	..	..	..	12.6
Maximum breadth	..	..	..	12.6
Length of hinge-line	..	..	..	8.8

Specimen too crushed to give accurate measurement of thickness.

The pedicle valve of this specimen is asymmetric due to the large cincatrix of attachment on one side of the umbo. It is evenly swollen in the middle with the sides and the front sloping steeply giving it a somewhat squashed appearance. The ears are small and flat with obtuse cardinal angles. The specimen is unfortunately badly weathered so that the ornamentation is obscured. Slender erect spines with approximate quinemicial arrangement are the obvious feature of the ornamentation, the concentric shell laminæ of the original shell surface, if these were present, being obscured. The

area is flat and lies in the plane of the commissures; it is interrupted by a triangular slightly convex pseudo-deltidium. Owing to the crushing of the brachial valve, the teeth are seen to be short, stout and diverging.

Even in its uncrushed form, the brachial valve must have been very concave. The ornamentation cannot be seen at all unless some pits due to weathering indicate that it was spinose. The area of this valve is as large as the pedicle area, with a well-developed pseudo-chilidium.

Comparison with other species.—This specimen resembles *Strophalosia beecheri* Rowley (Weller 1914, p. 146, pl. xix, figs. 37-38). Weller, in his description of this species, quotes its asymmetric character as a diagnostic feature. From his figure 37 it would appear that in that species, as in this specimen, the asymmetry is probably due to the eicatrix on one side. It is, however, a broader form than the present species and Weller says broader than long; but as he, too, had only one specimen, the variation within the species is not known.

Remarks.—This specimen has been compared to *Strophalosia beecheri*, but not identified finally as a member of that species since further specimens are required, both from America and Western Australia, before any definite identification is possible. More specimens, too, may establish the present specimen as a member of one of the variable Western Australian species.

Strophalosia clarkei (Etheridge).

Pl. v, fig. 4.

1872.—*Productus clarkei* Etheridge, p. 334, pl. xvii, figs. 2, 2a, 2b; pl. xviii, figs. 4, 4a.

1877.—*Productus clarkei* Etheridge, de Konink, p. 203, pl. x, fig. 5; pl. xi, fig. 3.

1878.—*Productus clarkei* (Etheridge), Etheridge, jun., p. 51.

1880.—*Strophalosia clarkei* (Etheridge), Etheridge, jun., p. 289, pl. ix, figs. 18-21; pl. x, figs. 22-28; pl. xi, figs. 29-31; pl. xii, figs. 32, 33.

1892.—*Strophalosia clarkei* (Etheridge), Etheridge & Jack, p. 258, pl. xiii, figs. 12-17; pl. xiv, fig. 19.

Holotype, belonged to Daintree Collection. Present location of type specimen not known.

Other Material.—B.M. B 5885, Capertree, N.S.W. (figured by Etheridge, 1880). Aus. Mus. F 36234, 36235, Jimba Jimba, near Mooka Springs, North-West Division, Gascoyne series.

Diagnosis.—Shell transversely oval to subquadrate, hinge-line less than greatest shell width. Pedicle valve inflated, without median sinus. Brachial valve flat to concave. Ornamentation of silky laminae on both valves.

Interior of pedicle valve with thin median ridge separating dendritic adductor muscle impressions. Diductors large, labellate and longitudinally striate. Teeth large.

Brachial valve with strong cardinal process continued into long median septum. Dental sockets large and oblique. Adductors high in valve. Brachial impressions strong, following edge of valve; valve geniculate with marginal rim perpendicular to visceral disc. Line of three depressions (adductor scars, depression below muscle scars and ends of brachial impressions) on each side of median septum.

Description.—Little can be added to the descriptions of this species in Etheridge (1880) and Etheridge and Jack (1892). The two specimens from Jimba Jimba are brachial valves whose external features are obscured by matrix. The internal features are as described by Etheridge. The characteristic structures of the valve are the line of three depressions (those of the adductor impressions, depression below the muscles and ends of brachial impressions) on each side of the median septum and the groove and marginal ridge on the outside of the brachial impressions. Inside the brachial impressions the shell is raised and prominent.

Comparison with other species.—The differences between this species and *Strophalosia kimberleyensis* mihi will be found under the heading of the latter species.

Etheridge (1880, p. 296) suggested that *Strophalosia gerardi* King and *Strophalosia clarkei* (Etheridge) were possibly one and the same species. The absence of any reliably identified specimens of *Str. gerardi* showing the internal characters led him to postpone a final decision in the matter. The situation of *Str. gerardi* is still the same, but these species may be distinguished by their external characteristics. *Strophalosia gerardi* has a relatively much shorter hinge-line, and its external ornamentation of oblique adherent spines on coarse concentric lamellae distinguishes it from the smoothly silky surface of *Str. clarkei*. Etheridge (1872) described the ornamentation of *Str. clarkei* as "covered with fine, vertical, wavy lines, projecting from which are numerous slender spines." This ornamentation I have not seen, weathering having removed apparently both the vertical lines and the spines. However, the description would certainly not fit the coarse adherent spines of *Str. gerardi*.

Strophalosia etheridgei n. sp.

Pl. V., figs. 5-12.

Syntypes.—G.S.W.A. 1/5242 (a), creek, $\frac{1}{2}$ mile west of Callytharra Springs, Woormel River, Callytharra Limestone.

Topotypes.—G.S.W.A. 1/5242 (b), same locality and horizon.

Other Material.—U.W.A., 20267, Fossil Cliff, Irwin River, Fossil Cliff horizon. U.W.A., 20247, Fossil Ridge, Irwin River District, Fossil Cliff horizon, Aus. Mus. F 38463, 38464, 38448, Wandagee Station, Minilya River, North-West Division, Wandagee stage.

Diagnosis.—Shell small, thin, transversely-oval to almost circular in outline. Hinge-line less than greatest width.

Pedicle valve flattish, evenly convex, non-sinuate, area relatively wide with narrow but not prominent pseudo-deltidium. Ornamentation of adherent spines interrupting silky laminated surface structure. Umbo not prominent, area of attachment small. Teeth small and diverging. Muscle scars deltoid in outline, non-dendritic, almost under umbo.

Brachial valve flat in visceral region with upturned margins. Ornamentation of silky laminae and concentric wrinkles. When weathered, valve pitted anteriorly. Cardinal process inclined, continued into short median septum. Sockets prominent, inclined at high angle. Muscle impressions rounded, at base of cardinal process.

Description.—The small size of this species is shown by the table of dimensions:—

—		Maximum width.	Length hinge-line.	Height.
<i>Syntypes:</i>				
1.	Conjoined valves	...	8.0	4.6
2.	Pedicle valve	....	8.5	5.7
3.	Brachial valve	....	6.7	5.0
4.	Conjoined valves	....	9.0	6.2
<i>Irwin River Specimens:</i>				
1.	Fossil Ridge	....	10.8 7.1 +	6.8 4.2
2.	Fossil Cliff	....	10.4 + 8.9 +	5.6 5.3
			15.9	11.0
				8.5 7.1 9.4 8.4 15.4
				Brachial Valves Pedicle Valve

The pedicle valve is small, thin-shelled and moderately inflated; it diminishes in convexity gradually towards the lateral and anterior margins, somewhat suddenly towards the cardinal margin. The area is small, narrow and triangular, its length less than that of the hinge-line. The shell substance is lamellar and has a silky texture, the laminae interrupted by the spines, which closely adhere to the surface of the shell. A few erect spines are present on the ears. The muscle scars are situated high up in the valve and have a deltoid outline, the delta divided medially by a groove into the two triangular areas. They are non-dendritic.

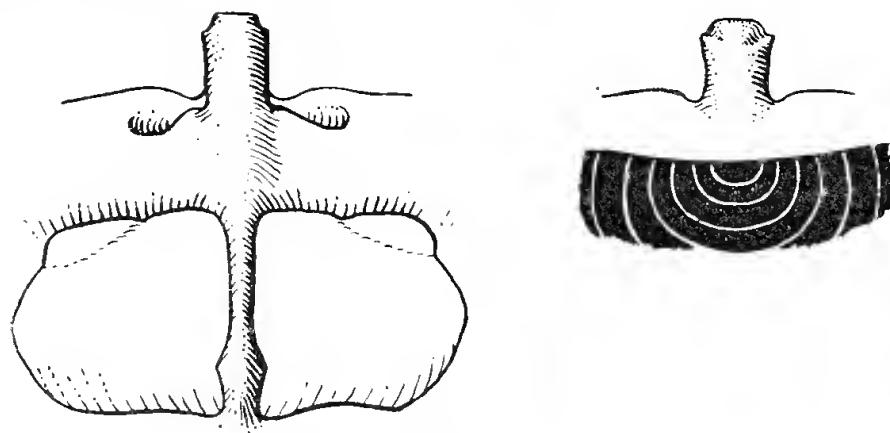


Figure 7.
Cardinal Process of *Strophalosia etheridgei* n. sp. ($\times 11$).

The brachial valve is flat in the viseeral region with geniculated margin and has a silky laminated and imbricated surface. The hinge-line is short and the cardinal angles are obtusely rounded. The area is distinct, triangular with the umbonal angle flattened; the pseudo-chilidium is triangular and wide with two deep, narrow sockets, inclined to the median septum at its base. The cardinal process is narrow near the hinge-line, but swells out to a

bulbous top. This is, however, usually worn down so that the process appears to continue posteriorly at an even width. The semi-circular visceral portion of the brachial valve is interrupted by the short median septum, which is swollen between the rounded muscle impressions. The valve is hollowed out below the sockets and in a direction parallel to the hinge-line, a ridge separating this hollow from the cardinal margin.

Comparison with other species.—The small size of these specimens distinguishes them from any species of *Strophalosia* so far described from Western Australia. They were labelled by Miss Hosking in the Geological Survey Collection, as being young specimens of a new species. The geniculated margin of the brachial valve indicates, however, that they are probably in the adult or nearing the adult condition unless they are the young forms of a *Proboscidella*-like *Strophalosia*. In the absence of any shells which might be assigned to such subgenus I have described them as adult forms.

Many features of these shells are also common to *Strophalosia clarkei* Eth. fil. and *Strophalosia gerardi* King, although they cannot be regarded as closely related to either of those species. The brachial valve particularly, with its silky lamellar structure, short hinge-line and rounded alar angles, resembles *S. clarkei*. The pedicle valve, however, would distinguish them at once from that species in its ornamentation showing a marked resemblance to *S. gerardi*; from young members of this species they would be distinguished by the shape and convexity of the pedicle valve.

Strophalosia gerardi King.

Pl. v, figs. 13, 16, 17.

1846.—*Strophalosia gerardi* King, p. 93 footnote.
 1847.—*Strophalosia gerardi* King, de Koninck, p. 137.
 1850.—*Strophalosia gerardi* King, p. 96, pl. xix, figs. 6-7.
 1857.—*Strophalosia gerardi* King, Davidson, Introduction, pl. viii, fig. 211.
 1880.—*Strophalosia gerardi* King, Etheridge, jun., p. 294, pl. xii, figs. 34-37; pl. xiii, fig. 38.
 1884.—*Strophalosia gerardi* King, Etheridge, jun., p. 87.
 1892.—*Strophalosia gerardi* King, Etheridge & Jack, p. 260, pl. xiii, fig. 18; pl. xiv, fig. 18; pl. xl, figs. 7-8.
 1932.—*Strophalosia gerardi* King, Reed, p. 20, pl. i, fig. 7.

Material.—*Holotype.* Univ. Coll. Galway, I.F.S., No. F.C.D. 267.

Diagnosis.—Shell outline transversely oval. Pedicle valve convex, non-sinuate; brachial valve concave following outline of pedicle valve. Ornamentation of concentric lamellae and adherent tapering spines. Area on both valves with pseudo-deltidium and pseudo-chilidium. Length of hinge-line less than maximum width of shell.

Pedicle valve swollen, with greatest convexity in visceral region, non-geniculate. Cardinal angles obtuse, ears small.

Brachial valve concave, greatest concavity near umbo, shell sloping thence gradually to all margins.

Internal features unknown.

Description of specimen.—Univ. Coll. Galway, F.C.D. No. 267. Viewed from the brachial side the shell is a regular oval in outline, the transverse axis passing postero-anteriorly. From the pedicle side it has rather a triangular aspect.

The pedicle valve is flatly convex, the maximum convexity behind the umbo, thence flattening gradually to the anterior and lateral margins and steeply to the cardinal margin. The area is short, equal in length to half the maximum width of the shell; it is relatively high with a very narrow, almost straight-sided pseudo-deltidium. The area of attachment is large, and has the appearance of callus over the shell surface. The ornamentation of the pedicle valve is essentially spinose, the spines adherent, with an irregular quincuncial arrangement. The structure of the shell surface is lamellar though the lamellae are largely obscured.

The brachial valve is concave. It slopes steeply from the umbo to the middle of the shell, thence following the curve of the pedicle valve. The shell structure is lamellar, but the valve is weathered, and no spine bases are seen, the ornamentation consisting of the truncated lamellae and irregularly spaced nodules. The area of the brachial valve is narrow but distinct. Internal features not shown.

Dimensions.

Height	..	..	30.4
Maximum breadth	..	..	38
Thickness	..	..	10.8

Etheridge says (1880, p. 296) that he finds "what appears to be the bases of insertion of spines" on the brachial valve of King's type specimen. It is difficult to come to a decision on this point from a study of the type specimen alone as, although there are hollows and small prominences on the lamellae, it seems almost impossible to decide that these prominences are or were spine bases. They show no concentric structure and no sign of aperture. It is noticeable, however, that where the spine bases are worn down on the pedicle valve, they, too, show no structure. On his figures of the Queensland specimens, too, Etheridge figures no specimen with spines on the brachial valve.

Strophalosia sp. cf. *Str. gerardi* King.

Pl. v, fig. 14, 15.

Material.—U.W.A., 12389. One pedicle valve. Fossil Cliff, Irwin River, Fossil Cliff horizon.

Description.—The shell is convex, non-geniculate, with the greatest convexity in the visceral region behind the cardinal margin. From this area of maximum convexity the surface slopes gradually to the anterior and posterior margins, but more steeply laterally. A large cicatrix covers the umbonal region. The area is concave with a well-marked pseudo-deltidium, at the base of which arise strong diverging teeth. The length of the area is about half the maximum breadth of the shell.

Dimensions.

Maximum width	..	..	31.7
Length of hinge-line	..	..	15.3
Height	..	..	27.0
Length of pedicle valve	..	..	38.9

The shell surface is lamellar with strong oblique spines arranged in irregular concentric rows. Posteriorly and on the cardinal slopes the spines are small and adherent; they become larger towards the anterior margin.

Internally the adductor impressions are seen high up in the valve; they are separated medially by a narrow groove. Longitudinal striations mark the shell at the side of the adductor impressions and are probably the impressions of the diductor muscles.

Comparison with other species.—This specimen has been referred to *Strophalosia gerardi* rather than identified with it. The general outline of the Irwin River shell is much broader than any specimen of *Str. gerardi*, and the spines are more widely spaced and less oblique than in that species. This specimen is possibly a local variant of *Str. gerardi*, but in the absence of intermediate forms cannot be satisfactorily united with it.

***Strophalosia jukesii* Eth. fil.**

Pl. v, figs. 18-20.

1880.—*Strophalosia jukesii* Eth. fil., p. 307, pl. xiii, figs. 39-43.

1888.—*Strophalosia jukesii* Eth. fil., Johnston, pl. xiv, fig. 7.

Syntypes.—B.M. 96874, 96931. New South Wales. Exact locality and horizon unknown. Figured by Etheridge 1880, pl. xiii, figs 39-43.

Other Material.—Commonwealth Palaeontologists' Coll. P. 14. Talbot's Cairn, Wooramel River District. U.W.A., 20264, same locality and horizon. U.W.A., 20266, same locality and horizon.

Diagnosis.—Shell elongate-oval in outline, hinge-line less than maximum shell width. Ornamentation of spines and concentric lamellae on both valves.

Pedicle valve evenly convex with flattening towards anterior margin and steep slope to cardinal margin. Area wide and distinct, pseudo-deltidium triangular. Ears small. Cardinal angles obtuse. Muscles high in valve, adductors central and compact, diductors flabellate and longitudinally striate.

Brachial valve concave, greatest concavity in front of umbo. Area distinct, half as wide as area of pedicle valve. Adductor muscle impressions divided into anterior and posterior sections. Cardinal process large, trifid, continuing into strong median septum.

Description.—A number of ferruginous casts have been referred to this species, as they agree in all particulars with Tasmanian specimens. For a complete description of the species see Prendergast (*Proc. Roy. Soc. Tasmania*).*

***Strophalosia kimberleyensis* n. sp.**

Pl. vi, figs. 1-5.

1890.—*Strophalosia clarkei* Etheridge, Foord, p. 103, pl. v, fig. 7-8, text-fig. 6.

1903.—*Strophalosia* sp. ind. Etheridge, jun., p. 20, pl. i, figs. 10-12.

Holotype.—U.W.A. 20452 north of Hill C, south side of Grant Range, Kimberley Division. Upper Ferruginous Series.

Paratypes.—U.W.A. 20460, same locality and horizon.

U.W.A. 20455, Nooncanbah Homestead, Kimberley Division. Nooncanbah Series.

Topotypes.—U.W.A. B 127.

Other Material.—B.M. B 4590, 4591, south-east of Mt. Abbott, on Fitzroy River, Kimberley Division. Horizon unknown. (Figured by Foord 1890). W.A. Mus. F 166 (4744), Cookilya Pool, Wandagee Station, Minilya River, Wandagee stage. (Figured by Etheridge, 1903). W.A. Mus. Δ 12, south-east of Mt. Abbott, Fitzroy River, Kimberley Division. Horizon unknown. Aus. Mus. F 37523-37529; Minilya River, Wandagee stage. Aus. Mus. F 36221-36225, Jimba Jimba Station, Gaseyne River, Byro stage. U.W.A. B. 51. Nooncanbah Homestead, Kimberley Division. Nooncanbah series.

Diagnosis.—Shell subquadrate to ovate in outline, pedicle valve inflated to hemispherical, brachial valve evenly concave, hinge line almost greatest width of shell.

Pedicle valve with lamellar concentric ornamentation; cardinal area elongate triangular with small triangular pseudo-deltidium. Internally with strong teeth, valve thickened postero-laterally with strong ridges bounding visceral portion laterally. Adductor muscles non-dendritic, narrow, on each side of median line; diductors longitudinally striate arising in front of adductors and extending from near middle line to lateral margin. Muscles set in distinct fossae.

Brachial valve with ornamentation as in pedicle valve. Valve thickened anteriorly, regularly concave exteriorly but geniculate interiorly. Cardinal process trifid, strong, with sockets at base; sockets separated by diagonal ridges from depressed muscular area. Posterior adductors elongate laterally, anterior adductors elongate antero-posteriorly. Brachial impressions arising from lateral edges of posterior adductors, following lateral and antero-lateral margins then turning backwards towards median septum. Septum continuing about two-thirds length of valve. Cineture separating visceral disc from trail.

Description of Holotype.—The holotype is an almost complete specimen with both valves in position. The pedicle valve is unfortunately weathered so that the external shell layers are absent. The valve is thick and of lamellar structure. The area is long and triangular, its width equal to one-fifth of its length; it has a narrow, closed, triangular delthyrum. The brachial valve is regularly concave and is ornamented by concentric lamellae, the edges of the lamellae forming the shell surface. It has a narrow area disposed almost at right angles to that of the pedicle valve.

Description of Paratypes.—The paratypes are two specimens, one a pedicle valve, the other a brachial valve, selected to show the internal features of the species.

In the pedicle valve (20460) the teeth are strong and diverging from the hinge-line; laterally they are joined to a projecting ridge separating the ears from the visceral cavity. The shell is thickened in the region of the ears, the ridge continuing as a platform to the lateral margin, its continuity being broken up by a narrow groove behind the ridge. This groove serves as a socket, a ridge on the brachial valve fitting into it. The muscle marks are distinct, the adductors elongate on each side of the middle line, arising almost under the teeth. The diductors are large, longitudinally striate, and anterior to the adductors they are separated by a rounded prominence in the middle line.

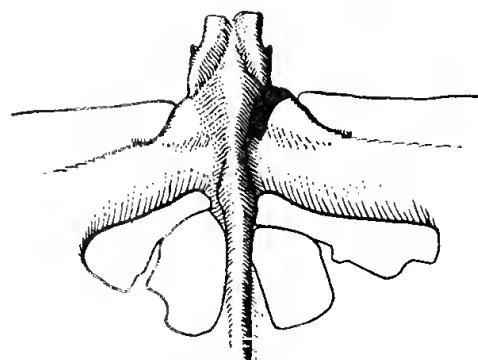


Figure 8.

Cardinal Process of *Strophalosia kimberleyensis* n. sp. ($\times 3$).

The interior of the brachial valve (20455) is geniculate, due to thickening of the lamellae in this region, a narrow groove (cincture) separating the visceral disc from the trail. In the visceral part the valve is almost divided by the median septum which continues forward for two-thirds of the length of the visceral disc; it is continued posteriorly as a trilobate cardinal process, at the base of which are deep sockets. The adductor muscles are below the sockets and set in a depression which gradually decreases anteriorly (this depression is bounded posteriorly by a ridge parallel to the hinge-line). The anterior adductors are elongate postero-anteriorly. The posterior adductors are elongate laterally and from their lateral extremities arise the brachial impressions. These continue the line of the ridge below the sockets until they almost reach the lateral border, they then follow the lateral and antero-lateral margins of the visceral disc and turn upwards parallel to the median septum. They cannot be traced in this specimen beyond the level of the end of the median septum.

Dimensions of Shells.

	Height.	Curvi-linear length of pedicle valve.	Length of hinge-line.	Max. width.	Thickness.
Holotype	28.2	56.0	22.0	27.8	10.8
Paratypes—					
20460	19.2+	31.0+	23.7	30.0	....
20455	24.3	....	24.5	29.3	....
Braehial Valves	29.3	....	29.4	35.7	....
	25.0	....	25.2+	28.1	....
Combined Valves	24.9	43.0	23.9	28.5	14.5
	29.0	46.0	25.9	28.8	14.4
	25.0	42.0	24.5	28.7	9.8

As may be seen from these figures, the height and width of the valve are the same in full-grown specimens, but as the maximum width is situated in the posterior half of the shell, younger specimens are wider than long.

The pedicle valve varies in shape from quadrangular to almost semi-circular and in convexity from weakly convex to hemispherical. As the shell becomes more strongly curved with age, the convexity is an indication of the age. There is, too, a difference in shape of some of the brachial valves due to the varying amount of thickening anteriorly; thus the valve may be regularly concave or slightly geniculate.

Owing to decortication of the shell surface, it is impossible to describe the true ornamentation of the shells. The lamellae are distinct on both valves and some specimens of the brachial valve show that these are crossed by very fine radial striae. A few only of these are seen, but they are continuous from one lamella to the next. One pedicle valve has, also, a small patch of radial ornamentation preserved. It is possible, therefore, that, were the shell surface preserved, the shell could be described as radially striate; alterna-

tively the radial markings may be the result of weathering. No pits, such as would indicate the presence of spines, have been observed and it would seem, therefore, that this species is non-spinous.

The variation within the species is also reflected in the internal structure of the brachial valve. The median septum may be equal in length to half or increase up to two-thirds of the length of the visceral disc. The brachial impressions may follow closely the lateral margin or be placed some distance from it.

Remarks.—The most peculiar characteristic of this species is the nature of the visceral cavity, the thickened region of the ears and the ridge projecting into the cavity. This may be seen externally, when the brachial valve becomes squashed in, showing the shape of the cavity.

Comparison with other species.—I regret that I have been unable to trace the type of *S. clarkei* (Eth.), which belonged to the Daintree Collection. Externally this species resembles *S. clarkei*, though it differs in many respects, as Etheridge (1903, p. 21) has already pointed out. With more and better specimens many of these distinctions cannot now be maintained, but this species, *S. kimberleyensis* is distinct in the depressed umbonal region, relatively longer hinge-line and concave rather than flat brachial valve. Internally, it occupies a position intermediate between *S. clarkei* and *S. jukesii*. In *S. clarkei* the median septum is as long as the visceral disc and the brachial impressions are transversely elongated; in *S. jukesii* the septum is short and the brachial impressions narrow. Thus in *S. kimberleyensis* with short median septum and wide brachial impressions we see a species with characters of both the other species. Externally the species is distinct from *S. jukesii* and *S. gerardi* in the absence of spines.

Strophalosia multispinifera n. sp.

Pl. vi, figs. 6-8.

Holotype.—U.W.A. 20458. Scarp two miles east of Christmas Creek Homestead, Kimberley Division. Nooncanbah Series.

Topotypes.—U.W.A. B 74. Same locality and horizon.

Other Material.—U.W.A. 20456, Hill C., south of road, Grant Range, Kimberley Division. Nooncanbah Series.

Diagnosis.—Pedicle valve large, swollen, transversely oval in outline, hinge-line less than greatest width of shell.

Ornamentation of fine oblique spines with regular quincuncial arrangement; group of spines on each ear. Valve with elongate area, triangular delthyrium. Cieatrix small. Teeth large. Brachial valve unknown.

Description.—The pedicle valve is evenly convex with a slight median depression, not sufficiently marked to be termed a sinus. It is 45 mm. high, with maximum width of 49.6 mm., while the hinge-line is 34.8 mm. long. The surface of the valve is marked by closely spaced spine bases arranged in irregular quincuncx; it is probable that these gave rise to small forward projecting spines, but no spines are preserved on the body of the shell. The spines have a density of 6 in 10 mm. measured transversely at a distance of 20 mm. from the umbo. The spines become more closely packed on the ears to give a compact group at each end of the hinge-line. They are closer together and more irregular anteriorly. The area is short, its width approximately half its length; it is longitudinally striated and interrupted by a

pseudo-deltidium which is not raised above the general surface of the area. Only one tooth has been seen; this is large and rounded with the concavity towards the lateral border.

The umbo is not prominent, having been absorbed by the cicatrix of attachment; this is small and usually almost perpendicular to the surface of the area.

The brachial valve is unknown.

Remarks.—Within this species there is a large variation in shape, many of the shells becoming elongated. It is noticeable that in this species, as in many *Strophalosias* (e.g., *S. kimberleyensis* mihi) the shells appear very narrow in the hinge region when seen as an internal cast. This is due to the very close fitting ears which leave almost no space between those of the two valves when these are in contact.

Comparison with other species.—This species is characterised by the regularity of the spines over the body of the shells, the spine groups on the ears, the small regular point of attachment and the absence of lamellar structure. It approaches nearest to *S. tenuispina* Waagen from which it may be distinguished by the much coarser spinosity of that species and the larger size of *S. multispinifera*.

STROPHALOSIA sp. A.

Pl. vi, fig. 10-12.

Material.—U.W.A., 20448 Fossil Cliff, Irwin River District. Fossil Cliff horizon.

Diagnosis.—Shell longitudinally oval in outline, evenly curved both transversely and longitudinally. Hinge-line less than greatest width of shell. Ornamentation of lamellae with fine adherent spines concentrically arranged. Pedicle valve swollen, non-geniculate, sides sloping steeply. Area narrow, triangular. Small divergent teeth.

Brachial valve unknown.

Description.—A single pedicle valve from the Irwin River District shows distinctive characters.

Dimensions.

Height	11.9
Maximum width	11.6
Length of hinge-line	6.3
Length of pedicle valve	18.6

The valve is swollen with the hinge-line less than the greatest width of the shell; the shell is widest near the anterior margin. The umbo is completely obliterated by a large scar of attachment, it has become incurved so that the area now faces antero-dorsally. The spines are regularly arranged in concentric rows and are all of equal size, there being no sign of a secondary series of spines as occurs in so many of the Indian forms. The rows are widely separated and between them are the silty laminations of the shell structure.

The area is well-developed with a wide delthyrum: the teeth are large and diverging. The muscle impressions are high in the valve. The adductors are central, separated by a median ridge and enclosed on the outside by the diductors, which are flabellate and produced anteriorly.

The distinctive characters are the widely spaced concentric rows of spines combined with the elongated shape of the shell.

Comparison with other species.—This shell appears most similar to *Strophalosia rarispina* Waagen (1884, p. 645) but the pedicle valve of that species has a slight median sinus and the spines are in two series.

***Strophalosia tenuispina* Waagen.**

Pl. vi, fig. 9.

1884.—*Strophalosia tenuispina* Waagen, p. 654, pl. lxiv, figs. 2-7.

Material.—U.W.A. 20451. One pedicle valve. Fossil Cliff, Irwin River. Fossil Cliff horizon.

Diagnosis.—Shell circular to oval in outline, hinge-line equal to maximum width, pedicle valve but slightly inflated, dorsal valve concave. Surface ornamentation finely lamellose with sparsely distributed oblique spines. Pedicle valve non-sinuate, area high, with flat, narrow linear pseudo-deltidium. Small scar of attachment.

Brachial valve with small linear area, surface ornamentation not known.

Description.—This species is known by a single specimen of a pedicle valve from the Irwin River.

Dimensions of Valve.

Height	..	..	..	17.8 [†]
Maximum width	..	..	..	21.3 [†]

The specimen is rather weathered, but shows the fine spines; these are represented now only as rather worn bases: the spines are all tangential to the shell surface and some of them adpressed. They are arranged more or less in concentric rows, each row separated from the previous one and that following by lamellae. On the lateral margins larger spines are developed, and these show a curious marking, almost a facet developed on the ventral surface of each spine. Whether this is the effect of weathering it is impossible to say. The spines, apart from their concentric arrangement, also show a roughly quinqueuncial arrangement.

The area of this species is very distinctive among *Strophalosias*, being flat and in the plane of the commissure of the valves. It is interrupted by a very narrow, parallel-sided pseudo-deltidium.

Comparison with other species.—For comparison of this species with *Strophalosia etheridgei* Mili, see account of that species.

ETHERIDGINA Oehlert.

1887.—Oehlert, in Fischer's Manuel de Conchylogie, p. 1278.

Genotype.—*Productus complectens* Eth. fil., 1876, On an adherent Form of *Productus* and a small *Spiriferina* from Scotland. Quart. J. geol. Soc. Lond., p. 454, pls. xxiv, xxv.

Diagnosis.—Shell small, concavo-convex, dorso-ventrally, with semi-oval marginal contour; generally as broad as long; hinge-line less than greatest width of shell. Shell attached to foreign bodies by embracing spines or by cementation of pedicle valve. Surface ornamentation of concentric undulating wrinkles. Area primarily present, with dental sockets and teeth. Muscle scars non-dendritic.

Description.—This genus was first described from the Carboniferous of Scotland and is now also known from the American Carboniferous and the Permian of Australia. The shells are always small and vary in their mode of attachment with the nature of the foreign body which acts as host. Thus, in the Scottish Carboniferous forms, where they occur more usually on crinoids, the spines along the hinge-line are greatly elongated and embrace the stem which may grow over and completely enclose the brachiopod. In the American forms (and in the Australian) on the other hand, which attach themselves to a flat surface, the shell is cemented directly by the whole of the pedicle valve—the spines along the hinge-line being produced parallel to the surface and adhering thereto.

The area, in those forms in which it has been observed, is narrow and extends along the total length of the hinge-line. In the pedicle valve teeth may be present or as is more usual in the Scottish forms they are represented only by vestigial or rudimentary small lumps.

Discussion.—In his original description of this genus Oehlert quotes the date as 1877; this was probably an error for 1887. In founding the genus, Oehlert referred it to *Productus*, it having, he thought, in common with that genus, the absence of area and of teeth and the pedicle valve not distorted by cementation.

The definition of the sub-family *Strophalosiinae* by Schuchert (1913) as productids anchored by spines or by most part of the pedicle valve, allowed *Etheridgina*, like *Chonopectus*, to be included in the subfamily without inferring any relationship to *Strophalosia* or indeed, any similarity other than that of habitat. Greger (1920, p. 535) referred a number of small adnate American species, formerly included in *Strophalosia*, to this sub-genus but accepted it as a sub-genus of *Productus*. Careful examination of the type specimens of the genotype of this sub-genus shows, however, that it should be referred to *Strophalosia* rather than to *Productus*. Several of the co-types (Royal Scottish Museum, Nos. 5074-5083) show a small though relatively well-developed area and teeth have also been seen on one specimen. Also the adductor scars of the brachial valve are non-dendritic. These features clearly distinguish it from *Productus* and show its relationship to *Strophalosia*. *Etheridgina* is, therefore, placed here as a sub-genus of *Strophalosia*.

In 1932 another productid sub-genus—*Leptalosia*—was proposed by Dunbar and Condra (1932, pp. 189, 190, 260) to include adnate productids attached by the whole of the pedicle valve. The members of this sub-genus had an area and hinge teeth in the pedicle valve of the older species (the sub-genus ranged from Upper Devonian to Carboniferous) and a distinctive small productelliform cardinal process. The genotype is *Etheridgina scintilla* (Beecher) (quoted by them as *Strophalosia scintilla* although this species had been referred to *Etheridgina* by Greger in 1920). The sub-genus, according to its authors, differs from *Etheridgina* in possessing a cardinal area and in the form of its cardinal process the resemblance of the two genera being homoeomorphic and the result of a similar habit of growth.

It is worth considering these differences further. As has been already mentioned, the type species of *Etheridgina* does possess an area. Dunbar and Condra (op. cit., p. 260) describe the productelliform cardinal process as "very small and bifid, composed of two narrow posteriorly facing and

closely adpressed muscular apophyses supported in front by a pair of very short diverging ridges separated by a depression." This clear definition is somewhat marred, however, by their statement (p. 192) that "as now conceived the genus (*Productella*) is undoubtedly a "Dump-box" for primitive Productoids and includes the ancestral radicles of several later genera." Which of these radicles, then, have they selected to typify the genus? In view of Kozlowski's work (1914) on the cardinal processes of *Productus* species this is a serious omission, as he has shown quite conclusively that not only does the cardinal process vary from species to species within a genus, but also with age among the members of any one species. On the other hand, Dunbar and Condra may consider that all the species of *Productella*, even with its present "dump box" composition, have a primitive type of cardinal process which therefore may be taken as characterising the genus; in other words, that Devonian Productoids of whichever "ancestral radicle" have the same type of cardinal process. And, significant in this issue, the only members of *Leptalosia* whose cardinal processes are mentioned in the description of the species are *L. truncata* and *L. radicans*, Devonian forms. It is just possible then that Dunbar and Condra have generalised about the Carboniferous forms from work on Devonian species. We do not know whether the cardinal processes of the American Carboniferous *Leptalosias* are of the same primitive pattern and cannot, therefore, yet separate them from the Scottish Carboniferous sub-genus *Etheridgina*.

One other point which might be produced in support of the separate existence of *Leptalosia* is the presence of teeth in the species of this genus, Ohlert having defined *Etheridgina* as "without cardinal teeth." The mistake in this case is Ohlert's, one of the co-types of *E. complectens* having at least the rudiments (or vestiges) of teeth, a condition also found among the Carboniferous forms of *Leptalosia*. In the face of this evidence I cannot regard *Leptalosia* as other than a synonym of *Etheridgina*.

Etheridgina muirwoodae n. sp.

Pl. vi, figs. 14, 15.

1914.—*Strophalosia* sp. Eth. fil., p. 34, pl. v, figs. 16-18.

1918.—" *Strophalosia complecte* s" Eth. fil., p. 253, pl. xl, figs. 11, 12.

Syntypes.—Ans. Mus. F 16699, three specimens; two are pedicle valves, one shows two conjoined valves, figured by Etheridge as *Strophalosia complectens* (pl. 40, fig. 12). Balmaningarra, Mt. Marmion, Kimberley Division. Horizon not known.

Topotype.—Ans. Mus. F 16812, one pedicle valve, figured by Etheridge as *Strophalosia complectens* (pl. 40, fig. 11). Balmaningarra, Mt. Marmion, Kimberley Division. Horizon unknown.

Other Material.—G.S.W.A. 10930, Mt. Marmion, Kimberley Division. Horizon not known. G.S.W.A. 10929, north of Barrabiddi, North-West Division. Horizon not known. Ans. Mus. F 38498, 38499, Wandagee Station, Minilya River, North-West Division. Wandagee stage.

Diagnosis.—Shell small, transversely oval to subquadangular in outline, adherent by body of pedicle valve and radiating marginal spines. Hinge-line less than greatest width of shell, with rounded alar angles.

Pedicle valve with upturned lateral and anterior margins, visceral region adherent, flat. Hinge area wide and flat, pseudo-deltidium large and triangular, teeth strong, divergent. Strong, long, adherent spines arising from cardinal margin. Muscle impressions raised.

Brachial valve eoncave, lamellar tending to nodular structure. Area and pseudo-ehilidium relatively large. Cardinal process inclined almost to horizontal; musele impressions small at base of cardinal process.

Description.—The pedicle valve is firmly affixed to the underlying shell in most cases and hence the ornamentation is not known. In one specimen (Aus. Mus. F 38498) the shell is geniculate and the trail is ornamented by fine concentric lamellae and stout oblique spines. The area is wide and flat, in length half the width of the valve and with a width one-fifth of the length. The area is marked by longitudinal striations, interrupted medially by a triangular deltidium.

The cardinal margin bears very long, slender spines which are cemented to the host. These have a length much greater than the length of the shell, one spine extending 1.3 em. from the margin. The spines occur in a mated group on the ears becoming more sparse towards the umbo; they arise perpendicular to the cardinal margin.

The teeth are strong, hollowed posteriorly to give a semi-ovoid cavity, and diverging. The musele impressions take a tetrahedral form, one apex of the tetrahedron towards the umbo and beneath the area. The muscular apophyses are slightly eoncave, they appear smooth and divided into a greater and a lesser part by a narrow ridge parallel to and near their anterior margins. The edge separating them is a thickened ridge simulating a median septum. The anterior face of the tetrahedron is narrow, and has curved side edges, due to the eoncavity of the apophyses. Any other markings on the inside of the shell have been obliterated.

The braehial valve has the shiny lamellar structure characteristic of so many *Strophalosias*. Superimposed on these lamellae are concentric wrinkles extending over the entire surface of the valve. The wrinkles are irregular in intensity giving a general impression of a nobbly rather than a lamellar structure. It is possible, although no evidence of their presence can be seen on this specimen, that spines were developed over part of the visceral disc. Marginal spines were present as shown by the numerous pustules. The brachial valve is swollen below the umbo into a strongly convex semi-spherical region whieh, undergoing rapid change of curvature, becomes flat and so continuing across the visceral disc upturns marginally. The area of the valve has a width about half that of the pedicle area; the ehilidium is triangular. If the valves are held in such a position that their height is vertical, the areas of both valves are in one horizontal plane.

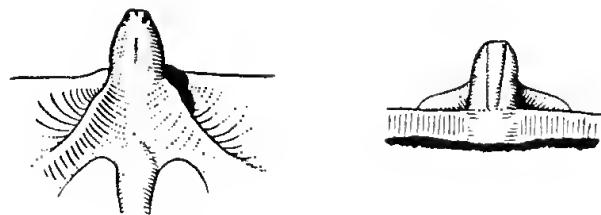


Figure 9.

Cardinal Process of *Etheridgina muirwoodae* n. sp. (X6).

The eardinal proeess is relatively large and is inclined almost at right angles to the area of the valves. It shows a characteristic trifid structure when viewed posteriorly, although the lateral arms adhere closely to the central

pillar. On each side of it are deep sockets each of which is bounded by a curved plate arising from the side of the cardinal process and making an angle with it of about 45° . A very short median septum is present, separating the muscle scars which lie close to the base of the cardinal process. These muscle impressions are not dendritic, nor do they show any division into anterior and posterior adductors. The brachial impressions are not preserved. Pitting is seen over some parts of the internal surface.

The dimensions of the shells are shown by the following table:—

Co-types.

	Conjoined valves.	Pedicle valves.		
Height	0·75	1·03+	1·10	0·58+
Maximum width	0·87	1·28+	1·41	0·92
Length of hinge-line	0·48	0·95	0·95	0·76

Variation within the species.—As may be expected in a closely adherent species the members of this species vary widely according to the nature of the host. The pedicle valve may be flat to highly convex (e.g. 10930); its area, though usually horizontal, may be highly inclined. It seems, too, that when the pedicle valve is closely adherent, it tends to assume the ornamentation of its host: thus, in G.S.W.A. 10930 B, where the host is a brachial valve of *Spirifer marconii* the pedicle valves exposed are corrugated to fit in between the striae. This feature is accentuated by weathering.

Comparison with other species.—It is with some trepidation that I have distinguished these specimens from other species of the genus, particularly as they had already been referred to *E. complectens* (Eth. fil.) by the author of that species. Their characters, however, are so distinct, that I have been forced to separate them. The specimens are larger and thicker-shelled forms than *E. complectens*; they possess relatively large and well-developed cardinal areas, strong teeth and characteristic muscular impression, in all these characters being distinct from *E. complectens*. The mode of attachment cannot be regarded as an important difference since, had the shells chosen a crinoid as host, it seems probable that the spines would encircle the stem, and we have as yet an insufficient number of specimens to say that they cannot or do not choose crinoid hosts.

The species heading of these specimens in Etheridge's description (1918, p. 253) is *Strophalosia complectens*, but elsewhere in the text and in the explanation of figures he gives *S. complectens*. I have assumed therefore that the title name was due to a typographical error.

It is possible that this species is really the adherent form of *Strophalosia etheridgei* mihi. The structure of the brachial valves of the two species are remarkably similar, the variations seen, such as the higher position of the muscle impressions and the more inclined cardinal process in *E. muirwoodae*, being probably modifications due to the assumption of a fixed habit. The external appearances of the two species differ only in the presence of spines in *E. muirwoodae* and this too may be due to the reason noted above.

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PLATE I.

Dictyoclostus callytharrensis n. sp.

Fig. 1. Brachial valve. Syntype. G.S.W.A. 1/4967 (b). (x $\frac{2}{3}$).

Fig. 2. Pedicle valve (x 1 $\frac{1}{2}$), to show ornamentation. G.S.W.A. 1/4654.

Fig. 3. Pedicle valve. Syntype. G.S.W.A. 1/4967 (b). (x $\frac{2}{3}$).

Fig. 4. Lateral view of Pedicle valve. U.W.A. 12400. (x $\frac{2}{3}$).

Fig. 5. Brachial valve (x 1 $\frac{1}{2}$), showing hinge-line and ginglimus. G.S.W.A. 1/4654.

Fig. 6. Hinge-line (x 1 $\frac{1}{2}$), to show ginglimus. Paratype. G.S.W.A. 1/4967 (a).

Fig. 7. Pedicle valve. U.W.A. 12400. (x $\frac{2}{3}$).

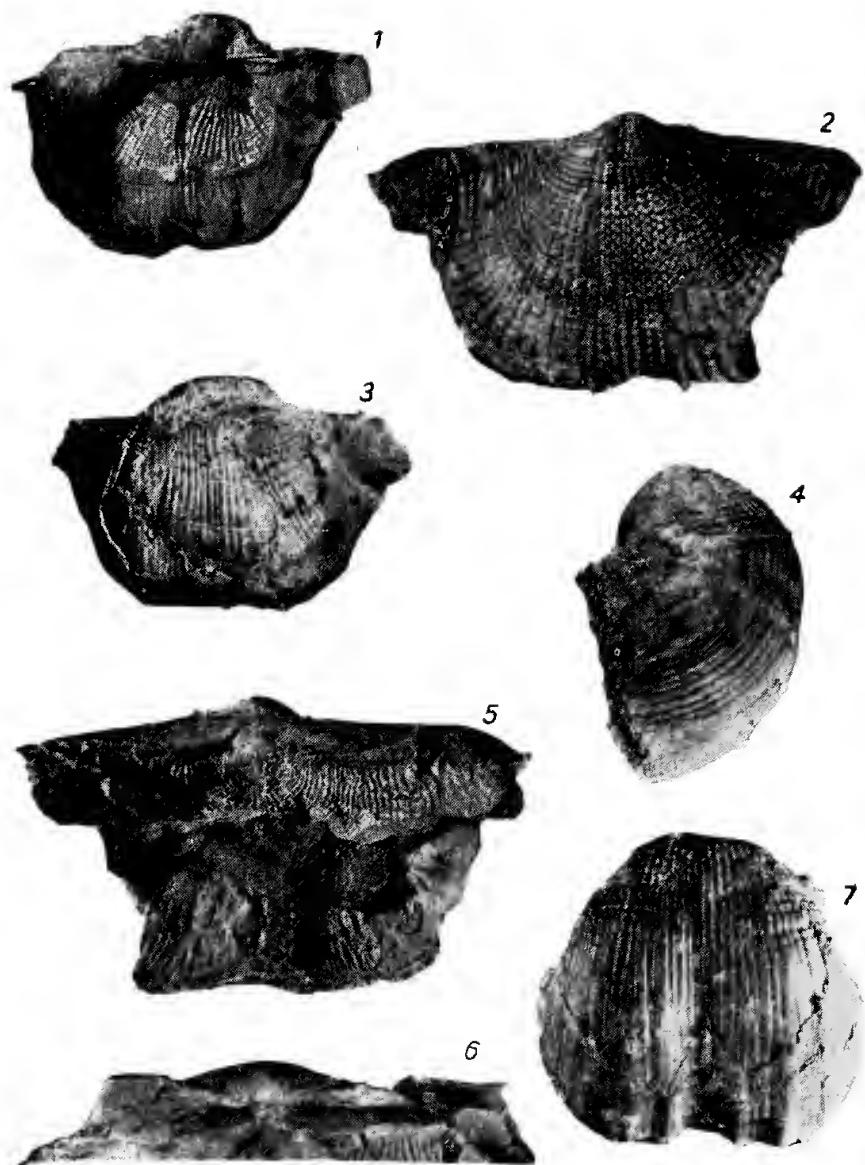


PLATE I.

PLATE II.

Fig. 1. *Dictyoclostus callytharrensis* n. sp. Pedicle valve (x 1 $\frac{1}{2}$). Paratype G.S.W.A. 1/4967 (a).

Figs. 2-4. *Dictyoclostus callytharrensis* var. *wadei* n. var. Holotype. U.W.A. No. 20453. (x $\frac{3}{2}$).
2. Hinge-line and umbonal region.
3. Lateral view of holotype.
4. Pedicle valve of holotype.

Figs. 5-7. *Dictyoclostus gratus* (Wangen). Ans. Mus. F. 37569 (x $\frac{3}{2}$).
5. Pedicle valve.
6. Lateral view.
7. Brachial valve.

Figs. 8-9. *Dictyoclostus spiralis* (Wangen). Ans. Mus. F. 36514 (x $\frac{3}{2}$).
8. Pedicle valve.
9. Lateral view.

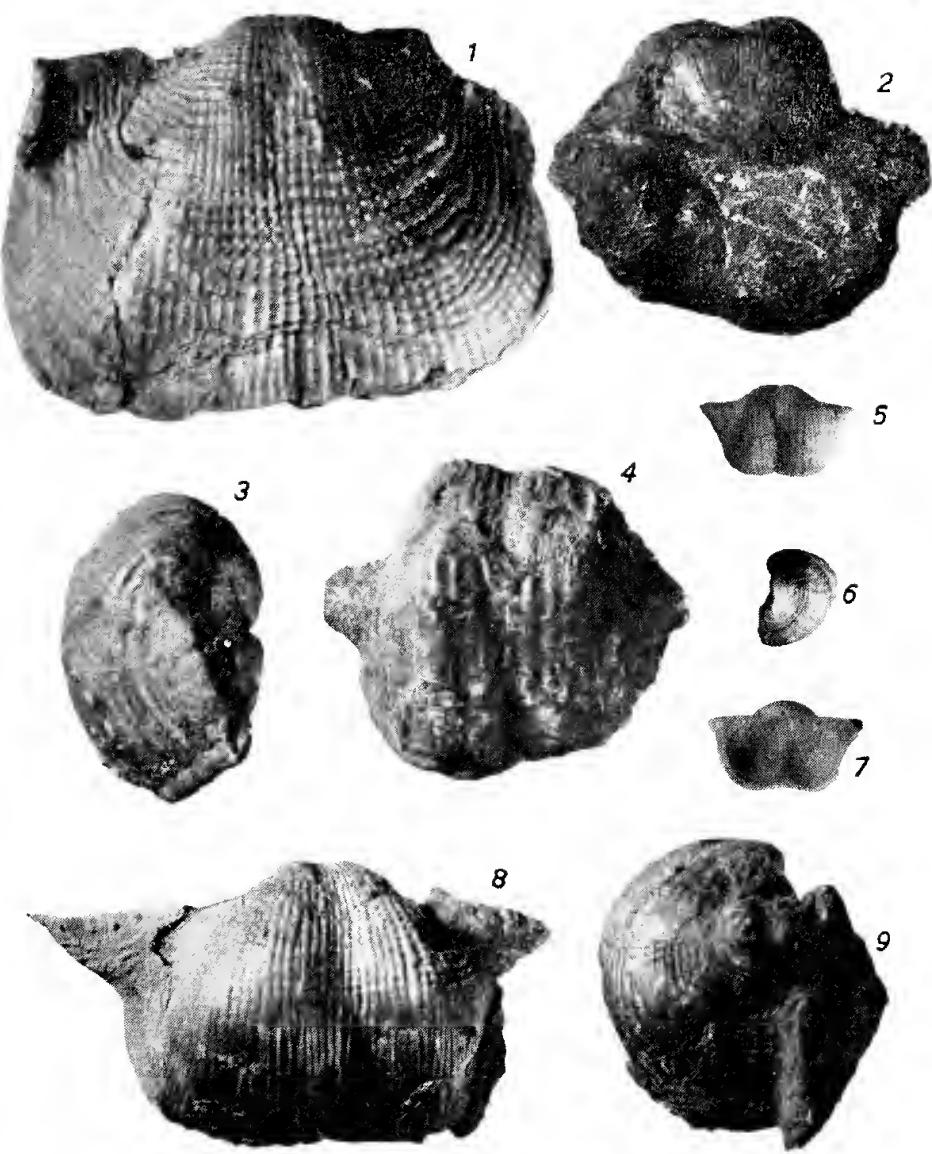


PLATE II.

PLATE III.

Figs. 1-2. *Linoprotectus canceriniformis* var. *lyoni* n. var. Holotype. Aus.
Mus. F. 36530. (x $\frac{2}{3}$).
1. Lateral view.
2. Pedicle and brachial valves.

Figs. 3-5. *Linoprotectus cora* var. *foordi* (Eth. fil.). G.S.W.A. 5708b. (x $\frac{2}{3}$).
3. Pedicle valve.
4. Brachial valve.
5. Lateral view.

Fig. 6. *Waagenoconcha vagans* Reed. Brachial valve. U.W.A. 20459. (x $\frac{2}{3}$).

Figs. 7-9. *Waagenoconcha imperfecta* Prendergast.
7. Pedicle valve. U.W.A., 20454. (x $\frac{2}{3}$).
8. Brachial valve. U.W.A., 20454. (x $\frac{2}{3}$).
9. Umbonal region of pedicle valve. U.W.A., 20457. (x $\frac{2}{3}$).

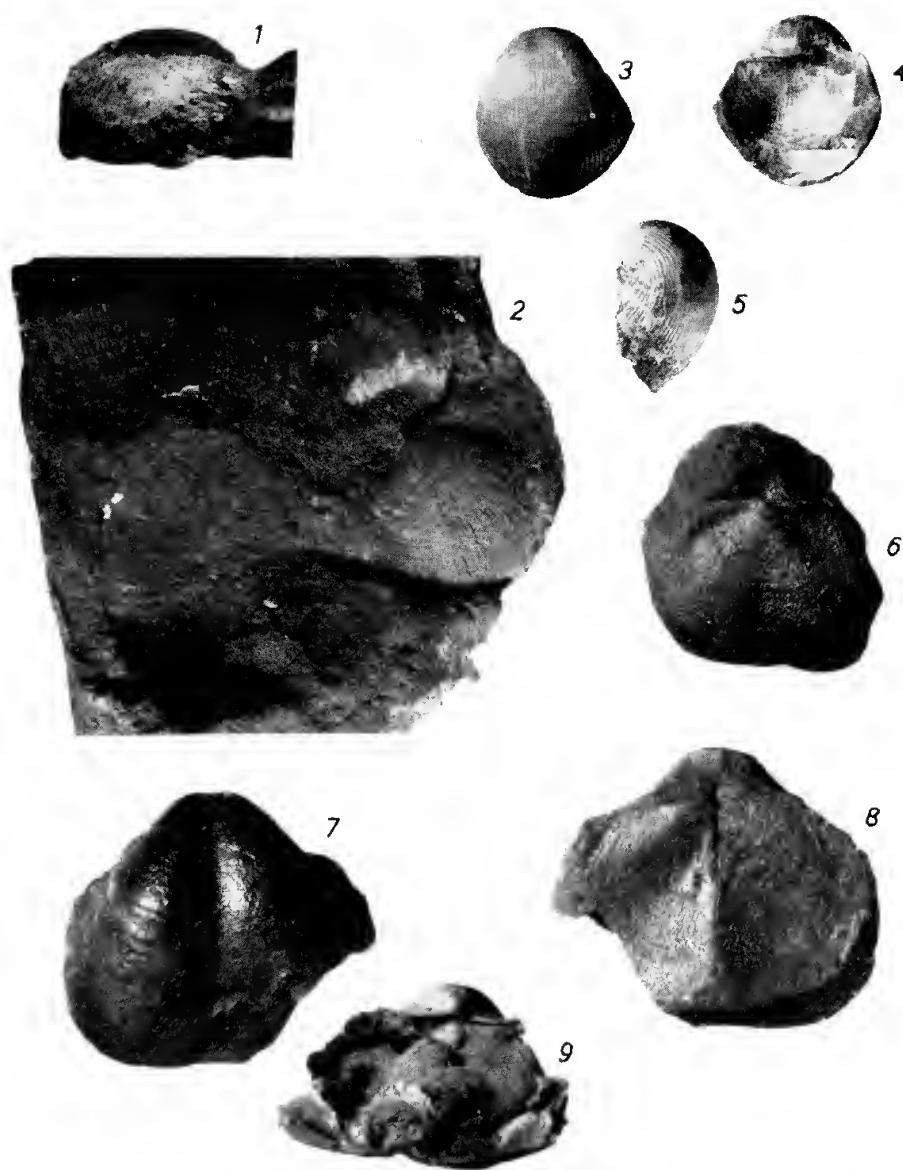


PLATE III.

PLATE IV.

Figs. 1-6. *Taeniothaerus subquadratus* (Morris).

1. Brachial valve, exterior. U.W.A. 12396.
2. Brachial valve, interior. U.W.A. 21247.
3. Interior of pedicle valve. U.W.A. 4786.
4. Pedicle valve, exterior. U.W.A. 20447.
5. Lateral view. U.W.A. 20447.
6. Hinge-line of crushed specimen. U.W.A. P. 21.

Figs. 7-10. *Aulosteges spinosus* Hosking.

7. Pedicle valve. Aus. Mus. F. 37710.
8. Lateral view showing recurved area. Aus. Mus. F. 37710.
9. Brachial valve. Aus. Mus. F. 38444.
10. Pedicle valve. Aus. Mus. F. 38444.

Figs. 11-13. *Krotovia spinulosa* (J. Sowerby). Aus. Mus. 38446.

11. Lateral view.
12. Pedicle valve.
13. Brachial valve.

All figures reduced to $\frac{2}{3}$ nat. size.

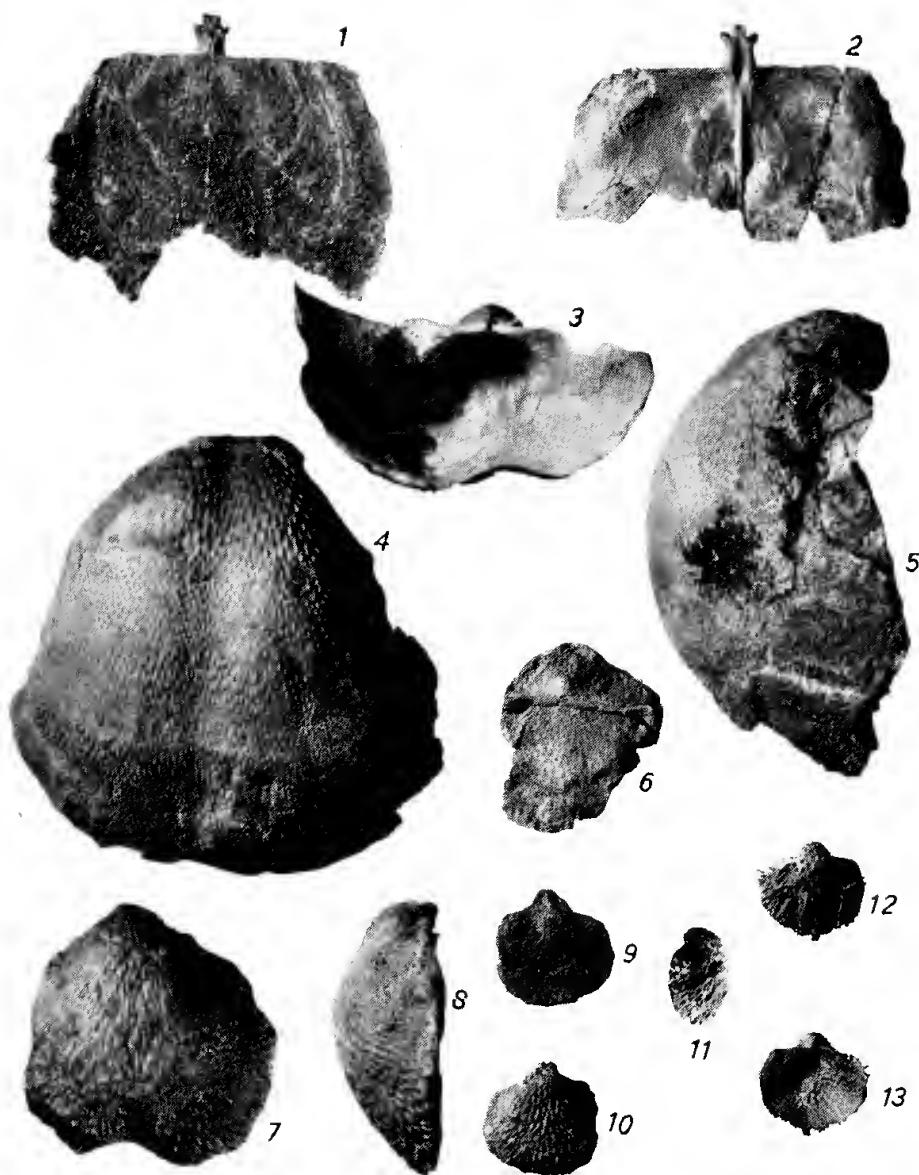


PLATE IV.

PLATE V.

Figs. 1-3. *Strophalosia* sp. cf. *Strophalosia bcecheri* (Rowley). U.W.A., 20449. (x $\frac{2}{3}$).

1. Brachial valve.
2. Pedicle valve.
3. Lateral view.

Fig. 4. *Strophalosia clarkei* (Etheridge). Interior of brachial valve. Aus. Mus. F. 36235. (x $\frac{2}{3}$).

Figs. 5-12. *Strophalosia etheridgei* n. sp.

5. Brachial valve in limestone. U.W.A., 20247(a). (x $\frac{2}{3}$).
6. Pedicle valve (x $1\frac{1}{2}$). Syntype. G.S.W.A. 1/5242 (a).
7. Interior of pedicle valve (x $1\frac{1}{2}$). Syntype. G.S.W.A. 1/5242 (a).
8. Lateral view (x $1\frac{1}{2}$). Syntype. G.S.W.A. 1/5242 (a).
9. Brachial valve (x $1\frac{1}{2}$). Syntype. G.S.W.A. 1/5242 (a).
10. Interior of brachial valve (x $1\frac{1}{2}$). Syntype. G.S.W.A. 1/5242 (a).
11. Brachial valve in limestone (x $\frac{2}{3}$). U.W.A., 20247 (c).
12. Pedicle valve (x $\frac{2}{3}$). U.W.A., 20237.

Fig. 13. *Strophalosia gerardi* King. Holotype. Univ. Coll. Galway, I.F.S. No. F.C.D. 267. Brachial valve and hinge-line. (x $\frac{2}{3}$).

Figs. 14-15. *Strophalosia* sp. cf. *Strophalosia gerardi* King. (x $\frac{2}{3}$). U.W.A. 12399.

14. Pedicle valve.
15. Hinge-line of pedicle valve.

Figs. 16-17. *Strophalosia gerardi* King. Holotype. (x $\frac{2}{3}$).

16. Lateral view.
17. Pedicle valve.

Figs. 18-20. *Strophalosia Jukesii* Eth. fil.

18. External cast of brachial valve. (x $\frac{2}{3}$). U.W.A., 20266.
19. Internal cast of brachial valve. (x $\frac{2}{3}$). U.W.A. 20264.
20. Internal cast of pedicle valve. (x $\frac{2}{3}$). U.W.A. 20264.

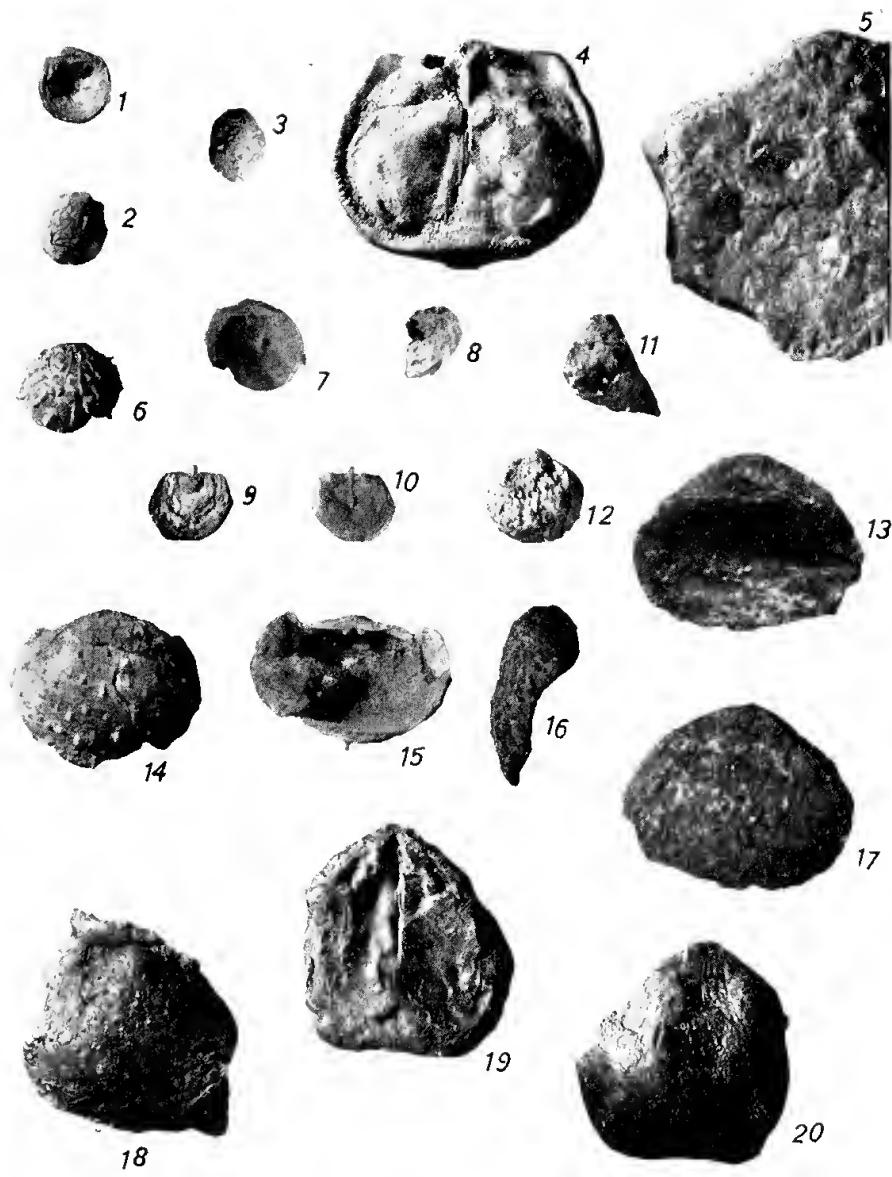


PLATE V.

PLATE VI.

Figs. 1-5. **Strophalosia kimberleyensis** n. sp.

1. Brachial valve. Holotype. U.W.A., 20452.
2. Pedicle valve. Holotype.
3. Lateral view. Holotype.
4. Interior of brachial valve. Paratype. U.W.A., 20455.
5. Interior of pedicle valve. Paratype. U.W.A., 20460.

Figs. 6-8. **Strophalosia multispinifera** n. sp. Holotype. U.W.A., 20458.

6. Lateral view.
7. Hinge-line.
8. Pedicle valve.

Fig. 9. **Strophalosia tenuispina** Waagen. Pedicle valve. U.W.A., 20451.

Figs. 10-12. **Strophalosia** sp. A. U.W.A., 20448.

10. Interior of pedicle valve.
11. Pedicle valve.
12. Lateral view.

Fig. 13. **Etheridgina complectens** (Eth. fil.). Syntype. Royal Scottish Museum No. 5080.

Figs. 14-15. **Etheridgina muirwoodae** n. sp. Syntypes. Aus. Mus. F. 16699.

14. Interior of pedicle valve and exterior of brachial valve.
15. Interior of pedicle valve.

All figures reduced to $\frac{2}{3}$ nat. size.

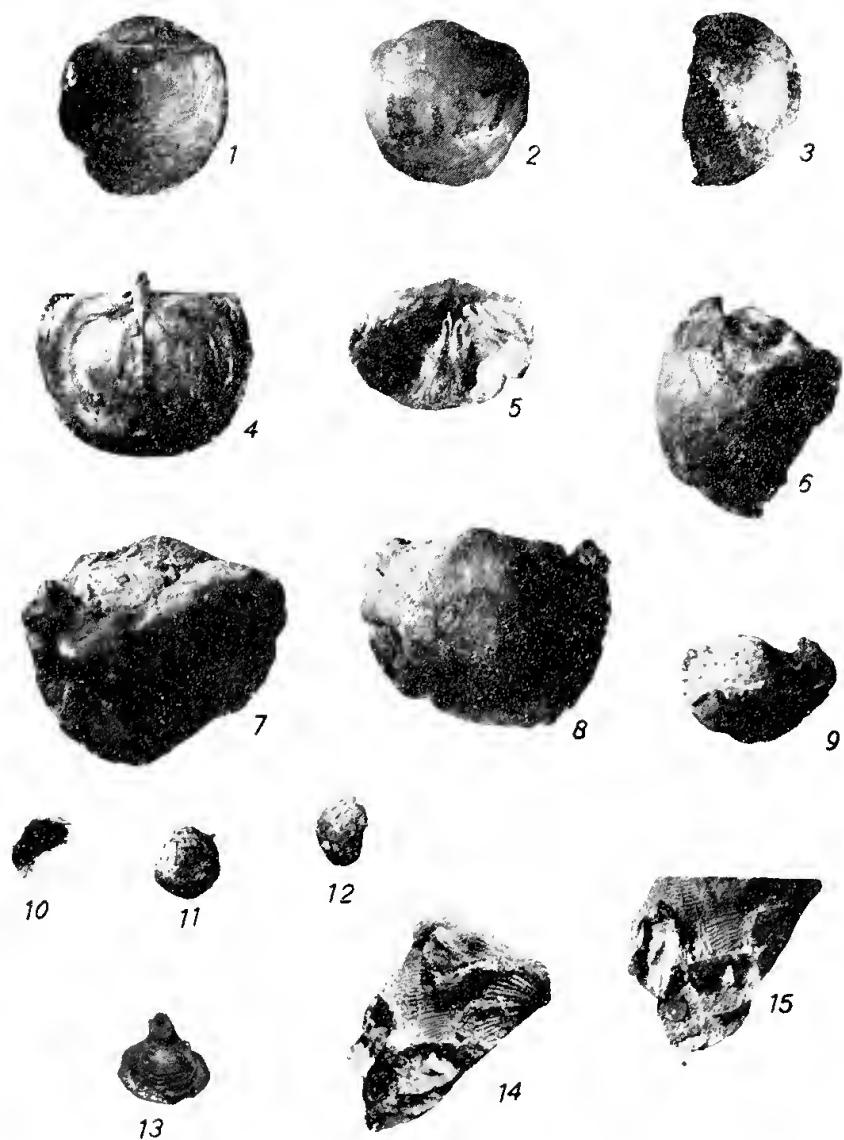


PLATE VI.



2.—THE OCCURRENCE OF THE GENUS CONOCYCLUS IN THE NORTH-WEST DIVISION, WESTERN AUSTRALIA.

BY IRENE CRESPIN, B.A., Commonwealth Palaeontologist.

Read 9th September, 1941; Published 21st May, 1943.

Communicated by Professor E. de C. Clarke.

In 1936, Mr. E. A. Rudd, M.Sc., when associated with Oil Search, Ltd., of Sydney, collected three specimens of a large echinoid from the east flank Cape Range, Exmouth Gulf Station, North-west Australia, whilst further examples were recently discovered in the same region by geologists attached to Caltex (Australia) Oil Development Pty., Ltd. All specimens have kindly been made available for examination. The tests are embedded in a pink to ochreous limestone containing species of Lepidocyclinae characteristic of the Middle Miocene in the Indo-Pacific. The form has been determined as *Conocyclus*, a rare genus only previously recorded from the Eocene in areas outside Australia.

The occurrence of *Conocyclus*, according to Morley Davies (1935) is "widespread in the Cretaceous, but unknown in Cainozoic of America or Australia." It is recorded from the Eocene of India, Egypt, Madagascar, Mozambique, and Persia, as well as from countries in southern Europe. "Its geological range thus follows the large *Nummulites* and like them, it never reached America and is apparently extinct after Middle Eocene."

All specimens are in the Commonwealth Palaeontological Collection, Canberra, Australia. The photographs of the types were taken by Dr. F. W. Clements, Australian Institute of Anatomy, Canberra.

DESCRIPTION OF SPECIES.

Plate I., figs 1-3.

Class ECHINOIDEA Brown.

Order HOLECTYPOIDA.

Family ECHINONEIDAE.

Genus CONOCYCLUS Agassiz.

Conocyclus westraliensis sp. nov.

Holotype.—Although a specimen has been selected as a holotype, the species cannot be fully described without referring to characters which are better illustrated in further specimens.

Test moderately large, almost circular in outline, broadest behind apical system above periproct; moderately convex to subconical on aboral surface, with a flat adoral face. Entire test covered with small tubercles sunken in rounded scrobicules. Apical system slightly praecentral or forward. Ambulacral and interambulacral plates only visible in worn specimens. Genital plate distinct with four genital pores. The two pore fields, which outline the five petals, are petaloid in shape. The pore fields, which are composed of pore pairs of the dot and dash type, in which one pore becomes slit-

like, are wide, extending from apex to ambitus, and converging towards apex and peristome. Peristome on adoral surface, central and pentagonal, with five interambulaeral bourelets, representing the rounded blunt projections from each ambulacrum adjacent to the peristome, and five ambulacral phyllodes, representing the ambulacral pores. The phyllodes indicate the petaloid arrangement developed on the aboral surface, and are distinct on one specimen. The five bourelets and five phyllodes form the floseelle. The periproct is on adoral surface at posterior end of test in the fifth interambulacral area close to ambitus.

Dimensions.—Height—Holotype, 49 mm.; Paratype, 41.5 mm.; Plesiotypes, (1) 41 mm., (2) 41.5 mm. Diameter of adoral surface from periproct to 3rd ambulacral—Holotype, 74 mm.; Paratype, 70.5 mm.; Plesiotypes, (1) 61 mm., (2) 66 mm.

Occurrence.—Holotype, Gorge east flank of Cape range, west of Exmouth Gulf Outcamp, North-west Division, Western Australia, coll. E. A. Rudd. (Com. Pal. Coll. No. 184). Paratype, same locality as holotype. (Com. Pal. Coll. No. 185). Plesiotypes, Open gorge, north of Mt. King, Cape range, coll. E. A. Rudd; 4.7 miles from mouth of Badjirrajirra Creek, Exmouth Gulf, coll. Caltex (Australia) Oil Development Pty., Ltd. (Com. Pal. Coll. Nos. 186, 187).

Observations.—Morley Davies states that "the genus is remarkable in having jaws of a Holoptyoid, the Cassidulinoid floseelle and Clypeastroid petals." The genus is typically represented in *C. westralsiensis*, the four specimens available for examination being uniform in shape but varying in height and diameter. Tate, in 1893, described from the Tertiary beds at Table Cape, Tasmania, an echinoid under the name of *Conoclypeus rostratus*. The specimen, which is in the Tate Museum, Geology Department, University of Adelaide, has been re-examined, and belongs to the genus *Echino lampus*. At the time when Tate described his form, the beds at Table Cape were considered Eocene in age, but they are now referred to the Miocene, being most probably Middle Miocene. The limestone in which *C. westralsiensis* is found, contains a foraminiferal assemblage typical of the Middle Miocene in the Indo-Pacific region and includes such forms as *Cycloclypeus postei* Tan and *Lepidocyclina (Tryblionepidina) martini* (Schlumberger). There is, therefore, little doubt that the genus ranges to a much higher horizon in the Tertiary in the Indo-Pacific region than previously considered.

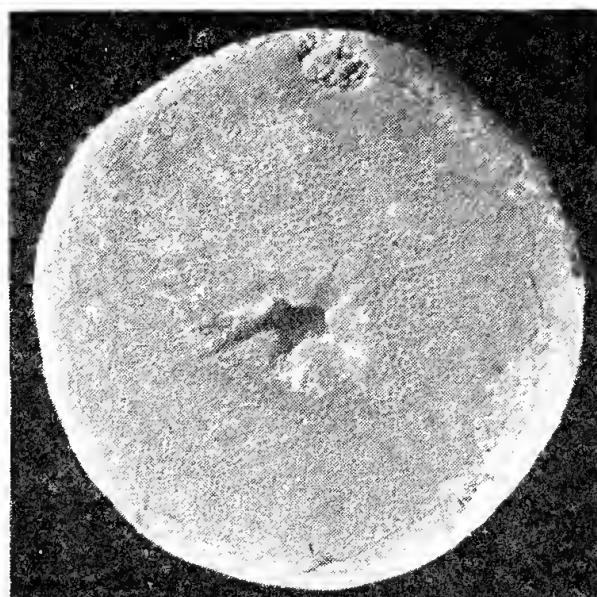
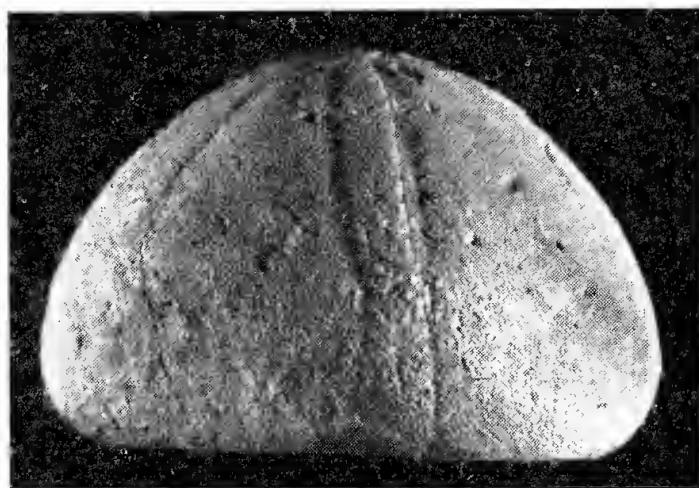
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DESCRIPTION OF PLATE.

All figures $\frac{7}{8}$ natural size.

Figs. 1-3. *Conoclypeus westralsiensis* sp. nov., Cape Range, Exmouth Gulf Station, North-west Division, Western Australia.
 „ 1. Side view of Holotype, showing typical *Conoclypeus* shape and characteristic surface ornamentation.
 „ 2. Adoral surface of paratype, showing peristome, periproct, 5 interambulacral bourelets and 5 ambulacral phyllodes.
 „ 3. Aboral surface of holotype, showing 4 genital pores and slightly praecentral apical system.



3.—FIBROFERRITE AND COPIAPITE FROM YETAR SPRING, NEAR CHIDLROWS.

BY REX T. PRIDER, Ph.D., B.Sc., F.G.S.

Read 14th October, 1941 : Published 21st May, 1943.

Yetar Spring (Lat. $31^{\circ} 56\cdot5'$ S., Long. $116^{\circ} 21\cdot4'$ E.) is situated in the upper reaches of the Helena River some $5\frac{1}{2}$ miles S.S.E. from the junction of the main Northam and York roads (see W.A. Govt. Litho. 2/80).

My attention was drawn to this locality by Mr. L. Burgess of Fauldings, Ltd., Perth, who collected encrusting material from the mound built up by this spring. This material, which Mr. Burgess gave to me for determination, proved to consist largely of a mixture of fibroferrite, copiapite, and melanterite. As this occurrence of fibroferrite was the first record of this mineral for Western Australia the locality was visited by Professor Clarke and myself in April of this year, and a closer examination of the occurrence was made.

THE MOUND SPRING.

The spring, situated on flat ground, several hundred yards south of the Helena, has built up a mound $1\frac{1}{2}$ chains in diameter and about 15 feet high (fig. 1). The mound consists of a black peaty earth which is a greyish colour when dried. This material, on ignition, yields a greyish diatomaceous earth consisting entirely of diatom remains and delicate rods of amorphous silica. The latter are broken and do not show any pointed ends or a central canal and are therefore not sponge spicules—they may be silicified plant fibres. A partial analysis of this diatomaceous earth (dried at $100^{\circ}\text{C}.$) gave :—

	%				
“Loss on Ignition” ...	...	...	...	...	21.85
SiO ₂ ...	...	...	...	...	69.71
Fe ₂ O ₃ ...	...	...	...	...	3.46
Rest ...	...	...	...	...	4.98
					<hr/> 100.00

Anal. : R. T. Prider.

According to the owners of this property, the mound from which the spring issues has gradually increased in size, apparently by growth from below, during the forty years that it has been known, so that several enclosing fences have been destroyed. About $1\frac{1}{2}$ chains west of the main spring there is another small spring and the ground surface over an area of about ten square yards is slightly uplifted.

The water from the spring is rich in solids (determined at 0.3077 parts per cent.) and qualitative tests indicate that chlorides are the dominant constituents with minor amounts of sulphates. The metallic ions present are mainly alkalies with lesser amounts of magnesium. No iron is present in the water, although in the channel through which the spring water runs over the surface of the mound there is a copious precipitate of flocculent iron oxide.

The sample collected by Mr. Burgess formed an encrustation on the peaty diatomite in the vicinity of the channel draining the water from the top of the

mound. It consisted of a mixture of white fibroferrite (predominant), yellow copiapite, and colourless melanterite. None of this material remained at the time of my visit in April, 1941 (possibly having been dissolved by rain, as these minerals are all water-soluble) and the only ferric sulphate minerals seen were from encrustations on the surface of small heaps of spoil from shallow holes which had been dug on the surface of the mound—such material consisted largely of copiapite and melanterite with no fibroferrite. Several samples were taken from the encrustations: (1) of moist yellow material, and (2) of dry earthy yellow material.

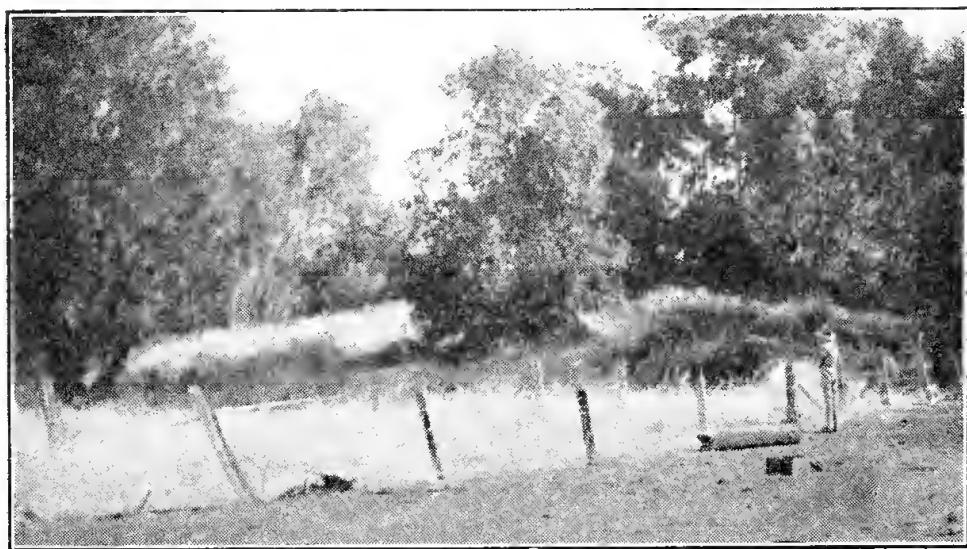


Figure 1.

General view of the mound at Yetar Spring. The figure on right gives the scale.

The ferric sulphate minerals are:—

A. *Fibroferrite*.—Present only in the sample collected by Mr. Burgess. It was identified optically and the determination checked by qualitative chemical tests. The properties of this mineral are:—

White in colour in the mass and soluble in cold water, the resultant solution giving positive reactions for $\text{Fe}^{''}$ and SO_3 only. Yields water and then SO_2 in the closed tube. Under the microscope it is seen to be in tiny colourless acicular forms with $\text{Z} \parallel$ length, $\gamma = 1.600 \pm .002$ and $\infty = 1.553 \pm .002$. These refractive indices are somewhat higher than those given by Larsen and Berman (1934, p. 103) for fibroferrite, viz., $\gamma = 1.575$ and $\infty = 1.533$.

None of the Yetar Spring fibroferrite could be obtained free from copiapite and no quantitative analysis has been made. The small lumps of white fibroferrite (about $\frac{1}{4}$ inch diameter) when broken are seen to contain a central core of copiapite.

B. *Melanterite* was identified optically from the samples collected by both Mr. Burgess and myself. My samples consisted entirely of copiapite and melanterite. In the damp material (sample 1) melanterite was more abundant than in the dry sample (No. 2) which consisted predominantly of copiapite with lesser amounts of melanterite. An estimation of ferrous iron in the moist material after drying in a desiccator over calcium chloride gave FeO

7.38 per cent. (as compared with FeO 4.50 per cent. in the naturally dry sample No. 2—see Table 1 below). The melanterite occurs as colourless weakly birefringent granules with refractive index 1.48.

C. *Copiapite* is the most abundant constituent of the naturally dried material (sample 2). It is earthy yellow material, soluble in cold water, yielding a brown acid solution. Under the microscope it is seen to be in microscopic yellow non pleochroic plates with high birefringence and $\gamma = 1.578$.

An analysis was made of the copiapite-rich sample (No. 2) and the result is shown in Table 1.

TABLE 1.

Analysis of Copiapite-rich Material (Sample 2).

Analysis on material dried in desiccator over calcium chloride for seven days.

		%	Mol. prop.	Melanterite.	Copiapite.	No. of Metal Atoms on basis of 6 S.
Insol.(1)	...	0.88	...	...	...	...
FeO	...	4.50	·063	·063	...	...
Fe ₂ O ₃	...	21.39	·134	...	·134	3.78
Al ₂ O ₃	...	Nil	...	...	...	...
CaO	...	Tr.	...	...	...	...
MgO	...	1.27	·032	...	·032	0.45
K ₂ O	...	0.25	·002	...	·002	0.06
Na ₂ O	...	2.17	·035	...	·035	0.99
SO ₃	...	39.17	·490	·063	·427	6.00
H ₂ O(2)	...	30.37	1.687	·441	1.246	35.10
Cl	...	Tr.	...	...	...	...
		100.00				

Anal. · R. T. Prider.

(1) Insoluble in cold water.

(2) By difference. A separate determination on another sample gave "loss on ignition" 65.82 per cent.

On the assumption that all of the FeO is in the form of melanterite the residue (copiapite) has the formula (Na₂, Mg)_{0.97}(OH)_{1.94}Fe³⁺_{3.78}(SO₄)_{6.00}·16.58 H₂O, which agrees fairly closely with the formula X(OH)₂.Fe³⁺₄(SO₄)₆·n H₂O suggested by Peacock (see Berry, 1939, p. 182). Following the nomenclature proposed by Berry (1939) this mineral would be a soda-magnesio-copiapite.

THE ORIGIN OF THE MOUND AND THE ASSOCIATED FERRIC SULPHATE MINERALS.

The mound surrounding the spring has apparently grown by addition of material from below. It appears most probable that the ferric sulphate minerals have been derived from a mass of pyritic material lying below the surface. The surrounding country (although outcrops are scarce in the immediate vicinity of the spring) is made up of Pre-Cambrian granitic rocks which would not be expected to contain any appreciable amount of pyrite—nevertheless pyritic masses are known to occur in the Darling Range granite, for example, at the Canning Dam quarry I have observed a well developed vein, several feet wide, of crushed granite heavily mineralised with pyrite. Again there may be a dolerite dyke carrying pyrites below the mound spring. Material derived from such a mass of decomposing pyrite has evidently been carried to the surface by the spring waters and deposited in the porous diatomite of the

mound. The ferric sulphate minerals crystallising throughout the porous diatomite would probably supply sufficient force to cause the slow uplift of the mound that has been observed.

ACKNOWLEDGMENTS.

I wish to acknowledge my thanks to Mr. L. Burgess for drawing my attention to this deposit. The expenses entailed by a visit to the locality were met by a Commonwealth Research grant for work on the Pre-Cambrian rocks of W.A. My thanks are due also to Professor E. de C. Clarke for his assistance in connection with the visit to the locality and during the preparation of this paper.

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4.—THE GEOLOGY AND PETROLOGY OF PART OF THE TOODYAY DISTRICT, WESTERN AUSTRALIA.*

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(Department of Geology, University of Western Australia).

Read 12th August, 1941: Published 14th March, 1944.

CONTENTS.

	Page
I.—INTRODUCTION	84
II.—GEOLOGICAL STRUCTURE OF THE AREA	85
III.—PETROLOGY	88
A.— <i>The Jimperding Series</i>	88
(I) Quartzites	88
(a) Upper quartzite	90
(b) The lower quartzites	91
(c) The origin of the quartzites	92
(d) The fabric of the quartzites	94
(2) Calc-silicate rocks	94
(3) Mica schists	97
(a) Sillimanite schists	98
(b) Garnet-plagioclase-biotite schist	99
(c) Gedrite-cummingtonite-plagioclase schist	100
(d) Andalusite schists	101
(4) Hornblende schists (plagioclase amphibolites)	104
(5) The Granite Gneisses and the associated xenoliths	107
(a) Upper Granitic Gneiss	108
(i) Biotite-microcline granite gneiss	108
(ii) Microcline granite gneiss	111
(iii) Biotite-oligoclase granite gneiss	111
(b) Xenoliths in the Upper Granitic Gneiss	111
(i) Schistose plagioclase amphibolites	111
(ii) Hornblende schlieren	112
(iii) Biotite granulite xenoliths	112
(iv) Eulysitic rocks	113
(c) Conclusions regarding the origin of the Upper Gneiss ...	114
(d) Lower Granitic Gneisses	114
(e) Xenoliths in the Lower Granitic Gneiss	115
(i) Eulysitic rocks	115
(ii) Calc-silicate rocks	118
(iii) Cordierite-anthophyllite rocks and related types ...	118
(iv) Amphibolite xenoliths	119
(f) Hybridisation of the Lower Granitic Gneiss	122
(g) Conclusions regarding the origin of the Lower Gneiss and the associated xenoliths	123
B.— <i>The Younger Igneous Intrusives</i>	124
(I) The granites	124
(a) The normal granites	124
(b) Garnet-muscovite granites	124
(c) Pegmatites, garnet aplites, and later quartz veins ...	124
(2) The greenstones	125
(a) Quartz dolerites	125
(b) Ultrabasic intrusives	128
(i) Metamorphosed ultrabasic sills	128
(ii) Serpentines	128
IV.—ECONOMIC GEOLOGY	129
(1) Gold	129
(2) Refractories	129
(a) Sillimanite	129
(b) Andalusite	129
V.—SUMMARY AND CONCLUSIONS	129
VI.—ACKNOWLEDGMENTS	131
VII.—LIST OF REFERENCES	132

* Part of the cost of publication of this paper has been borne by the Hackett Fund of the University of Western Australia.

I. INTRODUCTION.

The area which measures about 12 miles in an East-West direction, by three to four miles in a North-South direction, lies several miles to the south of the town of Toodyay, which is situated about 50 miles north-east from Perth. It is occupied almost entirely by a series of crystalline schists to which the name "Jimperding Series" has been given (Clarke, 1930, p. 167) and which is believed to be of an early Pre-Cambrian age. This series comprises pelitic and psammitic metasediments with intercalated basic and acid igneous bands. A study of the pelitic members shows that over the whole area mapped the rocks lie within the sillimanite zone.

This series has been intruded by granite (and its associated aplitic and pegmatitic dykes) and afterwards by a series of quartz dolerite and rare ultrabasic dykes—none of these igneous intrusions has metamorphosed the older rocks.

The only rocks of later age than the quartz dolerite series are of superficial character—laterites (durierust, Woolnough, 1930) and recent alluvial deposits. The durierust occurs at an elevation of about 900 feet above sea-level, and has been developed over all the older rocks, even the extremely siliceous quartzites. Neither it nor the alluvial deposits will be considered in this paper, which deals with the Pre-Cambrian rocks.

A brief account of the rocks from the western part of this area has been published (Prider, 1934, pp. 1-16) but, other than this, there is no account of the petrology of any of these Pre-Cambrian rocks. Simpson has described a number of the minerals occurring in the metamorphic rocks of the Darling Range, several from the area at present under consideration, viz., andalusite from Jimperding (Simpson, 1928, p. 50), sillimanite, also from Jimperding (Simpson, 1936, p. 10), and grossularite from Key Farm (Simpson, 1937, p. 32).

Clarke (1930, p. 167) shows that the Jimperding Series forms the greater part of the northerly extension of the Darling Range. From the vicinity of Toodyay, the rocks extend in a belt which has been traced as far north as the Irwin River District (about 200 miles north from Toodyay) and Ninganboun Hills (Simpson, 1931, p. 138). I have examined the rocks in the Irwin River District and they appear to be essentially the same as those developed at Toodyay.

To the south of Toodyay the Jimperding Series has been traced through Clackline (the series exposed here is the upper portion of the Jimperding Series) to York, a distance of 30 miles.

Previous to the publication of a paper by Forman (1937, pp. xvii.-xxvii.), the Jimperding Series had been regarded as the oldest formation in the Western Australian Pre-Cambrian shield. Forman (1937, p. xxv.) regards the "greenstones" of the Kalgoorlie Series as being older than the Jimperding (= Yilgarn) Series. Feldtmann (1919) describes a greenstone series at Bolgart (situated approximately 20 miles north from Toodyay) and correlates it with the Kalgoorlie Greenstone Series and Forman considers that these rocks probably underlie the Jimperding Series (1937, p. xxvi.). I have examined slices of some of the Bolgart rocks collected by Mr. R. W. Fletcher and find, in them, the counterpart of rocks occurring as xenoliths in the granitic gneisses in the Toodyay District—this would be confirmatory evidence that the Jimperding Series is younger than the Bolgart "greenstones," were it not that similar rocks are interbedded with the metasediments of the Jimperding Series.

This paper has been subdivided into two main sections, thus:—

I. The Geological Structure.

II. Petrology—

(A) The Jimperding Series.

(B) The later igneous intrusions.

In view of the variety of rock types developed in the area, theories of origin of each main group are discussed immediately after the description of typical members of that group and these theories are briefly recapitulated at the end of the paper.

II. THE GEOLOGICAL STRUCTURE OF THE AREA.

The regional strike throughout the Pre-Cambrian rocks in South-Western Australia is N.W.-S.E. In the area under consideration, there is a distinct departure from this N.W. regional strike, for, over a great part, the strike is more nearly E.-W.

A Pre-Cambrian metasedimentary series (the Chittering Series) has been described by Miles (1938) from the Chittering Valley, some 15 miles west from the Toodyay area. The dominant strike of these rocks is N. to N.W. These rocks are similar in character to the Toodyay rocks, but no information regarding the relationship of the Chittering and Jimperding Series is available, as the country between Toodyay and the Chittering Valley has never been geologically examined.

South of the Toodyay area, the Jimperding Series has been noted at Clackline and York and in both places the dominant strike is in a northerly direction.

It will be seen, therefore, that the Toodyay area is one of abnormal strike—unfortunately, field work has not covered a sufficient area to warrant any definite conclusions being drawn as to the true character of the structure, but in the following pages the structure is described so far as it is known.

From the geological map of the area (Plate I.), it will be seen that the whole area, except the S.W. corner, is occupied by a conformable series (note, however, that at a position about 300 chains W. and 80 chains N. of datum, the outer band of granitic gneiss appears to transgress the quartzite-hornblende schist-mica schist bands). The main structural features can be seen best in the accompanying sketch map (figure 1), which has been simplified from the more detailed, larger-scale, map.

Two wide bands of granite gneiss are interbedded with the metasediments—the banding everywhere conforming to that of the metasediments (except in the one place noted above). In the south-west part of the area, the boundary between granite gneiss and metasediment on the western side strikes nearly E.-W., but farther east the strike swings round to a south-easterly direction. The northern boundary of this upper gneiss band does not run parallel to the southern boundary, except in the westernmost part of the area. Towards the centre of the area it swings to the N.E. for a distance of approximately three miles and then turns sharply to a S.S.E. trend. The outer granitic gneiss (termed "Lower Gneiss" in figure 1) runs more or less parallel to the

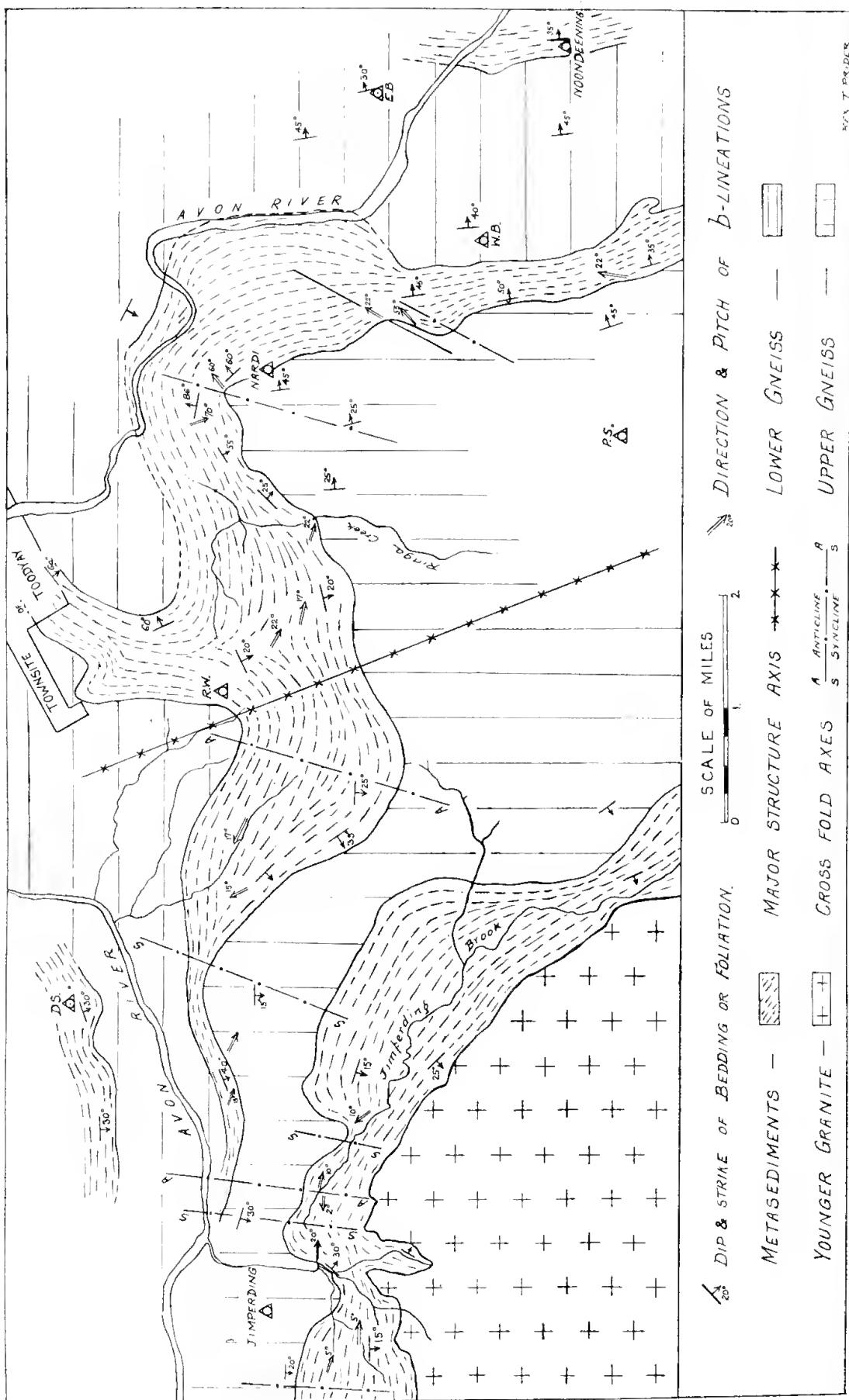


Fig. 1.
Structural Sketch Map of the Toodyay Area.

northern boundary of the upper granite gneiss and is bounded on both sides by metasediments, the dip and strike of which conform to that of the gneiss.

Regarding the dip of these rocks—in the western half of the area the dip is constantly south at amounts ranging from 15° to 40° ; in the centre of the area the general dip is at fairly flat angles to the south-east but there is a considerable amount of minor folding in the metasediments in this part; at the place where the strike suddenly changes to the S.S.E. in the N.E. part of the area the dips are very steep to the south, and thereafter fairly steep to the east.

From the field mapping the structure of this area is interpreted as:—

A major anticlinal structure (see figure 1), the axis of which traverses the centre of the area in a direction striking approximately N.N.W. and pitching to the S.S.E., which has, on its eastern limb, a recumbent syncline with its axial plane striking N.N.W. and dipping towards the east at approximately 60° . The axis of this fold also pitches to the south. The sequence as it appears in the eastern part of the area is therefore inverted. These structures are illustrated on the cross sections appearing with the geological map in Plate I.

This idea of the structure of the area would receive considerable support if it could be proved that the beds of the north and north-east parts of the area were older than those of the south-western parts. Up to the present, however, there is very little evidence other than that afforded by occasional drag folds, for determining the age relations of these rocks. Complete recrystallisation has almost obliterated graded bedding and similar structures which might have afforded criteria for determining the stratigraphical succession. (Some obscure current bedding structures have been noted but no certain interpretation of these was possible). All the rocks are in the sillimanite zone, and consequently grade of metamorphism affords no information as to the succession. Read (1936, p. 473) has pointed out that the abundance of andalusite in narrow pelitic bands may be due to graded bedding—the lower gritty positions of the band being almost free from andalusite, which becomes more abundant in the upper more pelitic part of the band, and he has applied this method to determining the stratigraphical succession in the Dalradian rocks at Banff. In the area at present under discussion this variation in size and abundance of andalusite in the upper pelitic rocks of the series is not present. As far as can be seen the rocks throughout this band are fairly uniform in composition. There is, as will be shown later, a constant variation in the development of the andalusite in this band, but this extends over a considerable width and is not due to any variation in the argillaceous components of the original sediment, but rather to a variation in the temperature conditions to which the rocks have been subjected.

Drag folded structures in the quartzites at a position 140 chains east and 225 chains south of datum indicate that the easterly dipping metasediments at that locality are on the western limb of an anticline overturned to the west and that the sequence in this vicinity is inverted.

If, as suggested by the drag folds at 140 E., 225 S., the rocks of the northern and eastern part of the area are older than those to the south-west (if they are not, the whole succession over the greater part of the area surveyed must be

inverted), then the order of succession, with approximate thickness of the individual beds is as follows:—

Upper	Andalusite-muscovite schist ....	....	....	....	> 250'
	Quartzite ....	....	....	....	500'
	Upper Granite gneiss (with rare basic igneous and meta-sedimentary xenoliths)	....	....	....	1900'
	Quartzite ....	....	....	....	110'
	Hornblende schist ....	....	....	....	40'
	Quartzite ....	....	....	....	570'
	Sillimanite schist ....	....	....	....	100'
	Quartzite ....	....	....	....	375'
	Lower Granite gneiss (characterised by the presence of basic igneous and sedimentary xenoliths)	....	....	....	5,400'
	Quartzite ....	....	....	....	650'
	Hornblende schist ....	....	....	....	35'
Lower	Quartzite ....	....	....	....	Unknown

These rocks form the Jimperding series and are intruded in succession by the following:—

1. Coarse non-foliated microcline granite.
2. Pegmatites, garnet aplites, and garnet muscovite granites.
3. Quartz dolerites.
4. Serpentinised ultrabasic sills and dykes.

The age relation of the quartz dolerite series and ultrabasites is not at present known.

Large scale faulting in the metamorphic rocks has been noted in several places, the most notable being in the part of the area situated about one and a-half miles east from Nardi Trig Station where a faulted block of the metamorphics is found. This block has suffered a displacement of approximately one and a-half miles along the fault plane (see E.-W. section through datum on Plate I.).

The lithology and structure of the area are reflected in the topography. The metasedimentary areas are all rough country, whereas the granite gneiss and granite areas are comparatively smooth. The main stream, the Avon River, as will be seen from the geological map (Plate I.) follows the structure very closely, and its main tributary (the Jimperding Brook) behaves in a similar fashion in the upper part of the series.

The distribution of the later quartz dolerite dykes is interesting in connection with the structure of the area. A glance at the geological map shows that they trend generally in a N.N.W.-S.S.E. direction. There are some exceptions to this, but the greater number of dykes have this trend. They have apparently come up along lines of weakness approximately parallel to the tectonic "strike" (or tectonic axis).

III. PETROLOGY.

A.—*The Jimperding Series.*

The metasedimentary members of this series, viz., the quartzites and mica schists will be described first and the igneous members (plagioclase amphibolites and granite gneisses) later.

(1) *The Quartzites.*

These are mostly coarse grained almost pure quartz rocks occurring in well defined bands. In the field they have a well bedded, flaggy appearance and are much jointed.

On all the bedding surfaces a well marked lineation (figure 2), due to elongation of mica flakes, is visible. This lineation is often accompanied by a corrugation of the surfaces of the quartzite flags. Unfortunately the significance of this lineation as pointed out by Phillips (1937, p. 591) was not appreciated at the time when the original field survey (made prior to 1936) was being carried out, but certain significant localities within the area have since been re-examined and the direction and pitch of these lineations noted. The light that these observations have thrown on the geological structure will be given in a later section.



Fig. 2.

Quartzite outcrop in Gorge Creek, near Key Farm, Toodyay, showing well marked b-lineations. The clinometer indicates the strike and rocks dip towards the observer in the direction of the arrow. The hammer handle lies in the direction of the b-lineations which pitch to the left-hand side of the outcrop. The well-marked jointing of the quartzites is a noticeable feature. (Reproduced from "Junior Geology" by E. de C. Clarke and L. F. Hanrahan, by kind permission of the University of Western Australia Textbooks Board.)

The structure in all the specimens examined microscopically, is similar, viz., coarsely granoblastic consisting almost entirely of irregular interlocking grains of quartz. All signs of elastic structure have been completely obliterated by recrystallisation. In all the rocks examined there is slight undulatory extinction, but no other signs of crushing in the quartz. A pale greenish chrome muscovite is the most common constituent other than quartz, and is present in all the specimens examined. Occasionally narrow seams up to 2 inches thick of this mica are interbedded with the quartzites. Felspar (mainly microcline with a little oligoclase) is a common constituent, but rarely exceeds 5 per cent of the rock. Minor minerals present in varying amount, are magnetite, apatite, rounded pink zircon, biotite, and rutile. These "heavy" minerals are occasionally concentrated into bands (figure 4B).

In the earlier examination of these rocks from the Jimperding Area, it was thought possible to distinguish the various quartzite bands by means of the minor constituents (Prider 1933, p. 7). Extension of the survey and an examination of a greater number of the lower quartzites has indicated that,

while possible to distinguish between the uppermost horizon and the bands in the lower part of the series, these lower members could not be distinguished from one another.

In this paper, therefore, the quartzites will be considered in two main groups:—

- (a) The upper quartzite (No. 5 quartzite of the earlier paper).
- (b) The lower quartzite horizons.

(a) *The Upper Quartzite* is characterised by the mode of occurrence of chrome muscovite and almost complete absence of felspar. These rocks are all even, coarse-grained types, consisting almost wholly of quartz, in which the average grain size is of the order of 3 mm. diameter, although much coarser varieties are often encountered. The remarkable evenness and coarseness of grain indicate the high degree of metamorphism to which these rocks have been subjected (Harker, 1932, p. 67).

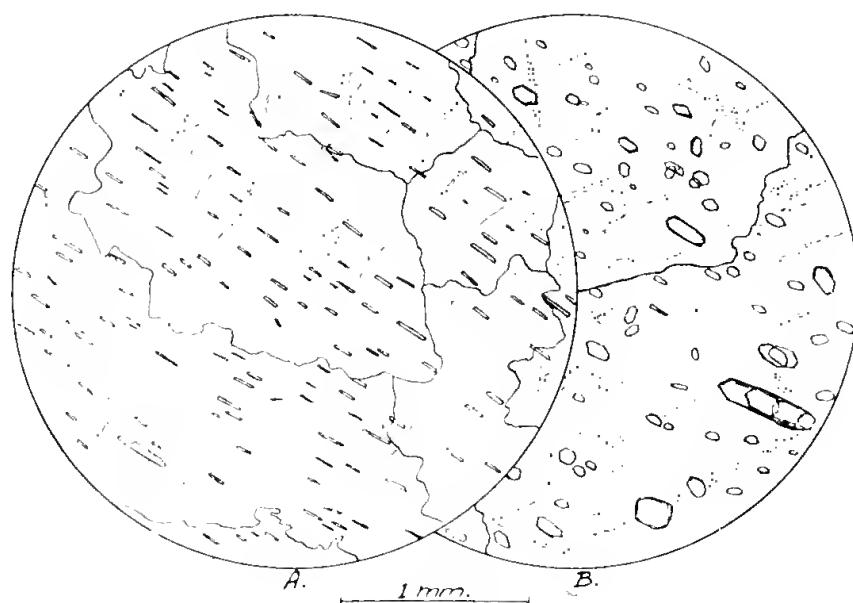


Fig. 3.

A. Micaeous quartzite. Section perpendicular to bedding. Shows the coarse granoblastic structure and parallel oriented rods of chrome-muscovite.

B. Micaeous quartzite. Section parallel to bedding showing tendency of idioblastic mica to be elongated in a common direction (= direction of lineation seen in hand specimen.)

Under the microscope the irregular interlocking quartz grains frequently exhibit a marked elongation in sections cut normal to the bedding. Undulose extinction often accompanied by incipient cracking is a common feature. Minute dusty inclusions, many of which are gas-liquid inclusions, are always present and appear to be arranged in lines normal to the direction of elongation of the grains (figure 3A). These appear to be directions of tension joints ("ac joints") as described by Fairbairn (1937, p. 89), although this cannot be verified until fabric analyses of these rocks are made.

The presence of abundant chrome muscovite inclusions in the quartz grains is the most remarkable feature of the upper quartzites. These are all arranged in parallel orientation as shown in figures 3 (A) and (B). In

sections normal to the bedding the mica appears in innumerable minute parallel rods. Sections parallel to the bedding (figure 3B) show that the minute mica flakes are all euhedral and the marked lineation noticed in the hand specimen becomes evident under the microscope in the elongation of these flakes in a common direction.

The mica, in hand specimen, is a pale bluish-green colour, but under the microscope it appears colourless, except in thicker sections, when it has a bright light greenish colour with pleochroism:—

X pale bluish; $Y = Z$ pale yellow-green; absorption $X \leq Y = Z$.
 $\beta = 1.606$; $(-2V = 31^\circ - 33^\circ)$; Dispersion distinct $r > v$.

A determination of the Cr_2O_3 content of mica isolated from a narrow band (2 inches wide) of chrome mica in one of the Lower Quartzites gave—

$\text{Cr}_2\text{O}_3 \quad 0.22$ per cent.

This is considerably lower than the Cr_2O_3 of the normal chrome muscovites quoted by Doelter (1917, p. 428). Of the six analyses quoted, the lowest, Cr_2O_3 , is 0.87 per cent, and it goes as high as 3.95 per cent in the original fuchsite from Zillerthal. Hutton (1940, p. 330B) has described a chrome muscovite containing 0.27 per cent Cr_2O_3 and has noted how even a very small chrome content is sufficient to produce a bright green colour in a thick flake of the mineral.

Partridge (1937, p. 457) has recently described a similar mica from Mashishimala, Transvaal. It carries 0.85 per cent Cr_2O_3 and Partridge considers that chrome muscovite is a better name for this mineral than fuchsite as it was previously termed. In its optics: Pleochroism X blue, Y yellowish green, Z bright green (bluish), $\beta = 1.596$, $(-2V = 35^\circ)$: it agrees closely with the mica in the Toodyay quartzites. The chrome muscovite, according to Partridge, occurs quite commonly in the quartzites of the Swaziland System in South Africa and it is therefore similar in occurrence to the chrome-muscovite in the Toodyay quartzites.

The source of the chromium, which is so widely disseminated through these quartzites, is unknown—no chrome-bearing detritals have been noted in these rocks and no ultrabasic rocks (other than several small bodies younger than the quartzites) are known in the area. Partridge (1937, p. 459) has noted the presence of traces of chromium in minerals connected with, and contained in, the granites of North-East Transvaal, and also that the occurrences of chrome-muscovite are connected with the granite intrusions and are found only in close proximity to the granite—he concludes, therefore, that the chrome-muscovite is genetically related to the granite.

An interesting association of tourmaline with the chrome muscovite was noted in the quartzites in the Gorge at Key Farm—here a few platy crystals of tourmaline up to 2 cm. long, coated with the greenish mica, were found on the bedding surfaces of the quartzites. The tourmaline is a slightly chromiferous pale brownish schorl with $\epsilon = 1.659 \pm .002$, $\omega = 1.615 \pm .002$, containing 0.35 per cent Cr_2O_3 . This occurrence seems to support the possibility that the chromium was derived from the granitic gneiss intrusions (or from its pegmatitic derivatives which are particularly numerous in the Gorge Creek locality at Key Farm, where the green muscovite is also more abundant than elsewhere).

(b) *The Lower Quartzites.*—There are six distinct bands in the lower part of the series. They are interleaved with sillimanite schist, hornblende schist (plagioclase amphibolite), and thicker granite gneiss bands.

They are mostly coarse grained types (average grain size 3 mm. or more) and have the same granoblastic structures as noted above, the main differences to the Upper Quartzite being the almost constant presence of felspar in the Lower Quartzites and its absence in the Upper Quartzite and the fact that the chrome muscovite in the Lower Quartzites is generally set between the quartz grains while in the Upper Quartzite it occurs as inclusions in the quartz.

Most hand specimens are very coarse sugary rocks with bedding planes sparsely coated with pale greenish chrome-muscovite. White turbid felspar is a common constituent, but is never present in amounts exceeding five per cent. It is usually a microcline, but rare grains of oligoclase and orthoclase are present. The felspar grains are much smaller than the quartz, reaching a maximum of about 0.5 mm. diameter—they are usually somewhat rounded, slightly turbid inclusions in the quartz, but the larger grains show a tendency to idiomorphism (figure 4A).

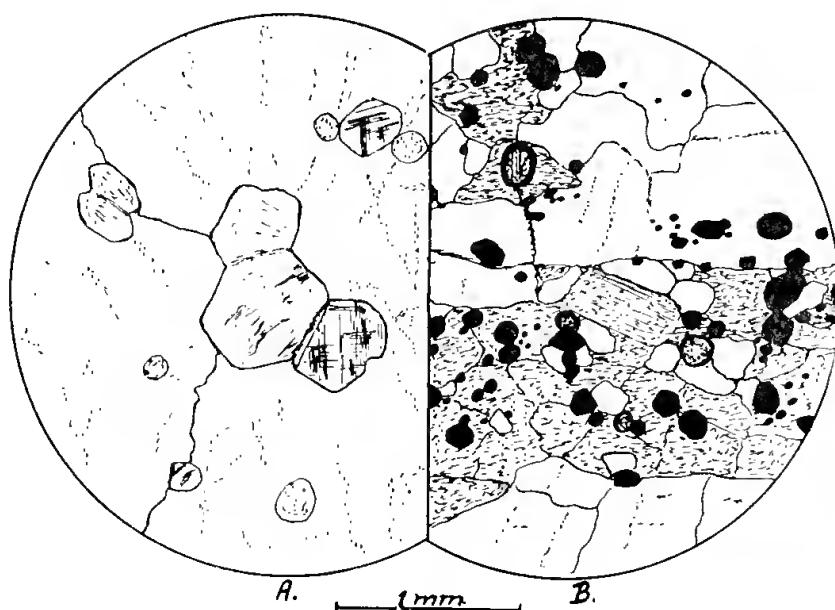


Fig. 4.

A. Felspathic quartzite, showing coarse granoblastic structure and tendency of larger microclines to assert their crystalline form.

B. "Heavy mineral" band in lower quartzite.

Minor detrital minerals occur sparsely in these lower quartzites—the most common species are rounded grains of zircon, magnetite and rutile. Pyrite in rounded grains with a thick rim of limonite is found occasionally—there can be little doubt, in view of the rounding of the grains, that the pyrite is an autochthonous constituent of the rock. The segregation of these "heavy" minerals into bands (figure 4B) has been previously noted.

(c) *The Origin of the Quartzites.*—The quartzites, then, are rocks of simple composition consisting almost entirely of quartz (95 per cent +). There can be little doubt that they were originally remarkably pure sands which have been completely recrystallised in the sillimanite zone. The coarse granoblastic structures, which have completely obliterated any sign of original clastic structures, testify to the high grade of metamorphism to which they have been subjected. In the absence of any foreign material, the only change in these rocks is the complete recrystallisation of the quartz. Hall and du Toit (1923, p. 77) in describing the very coarse quartzites at the base of the Bushveld

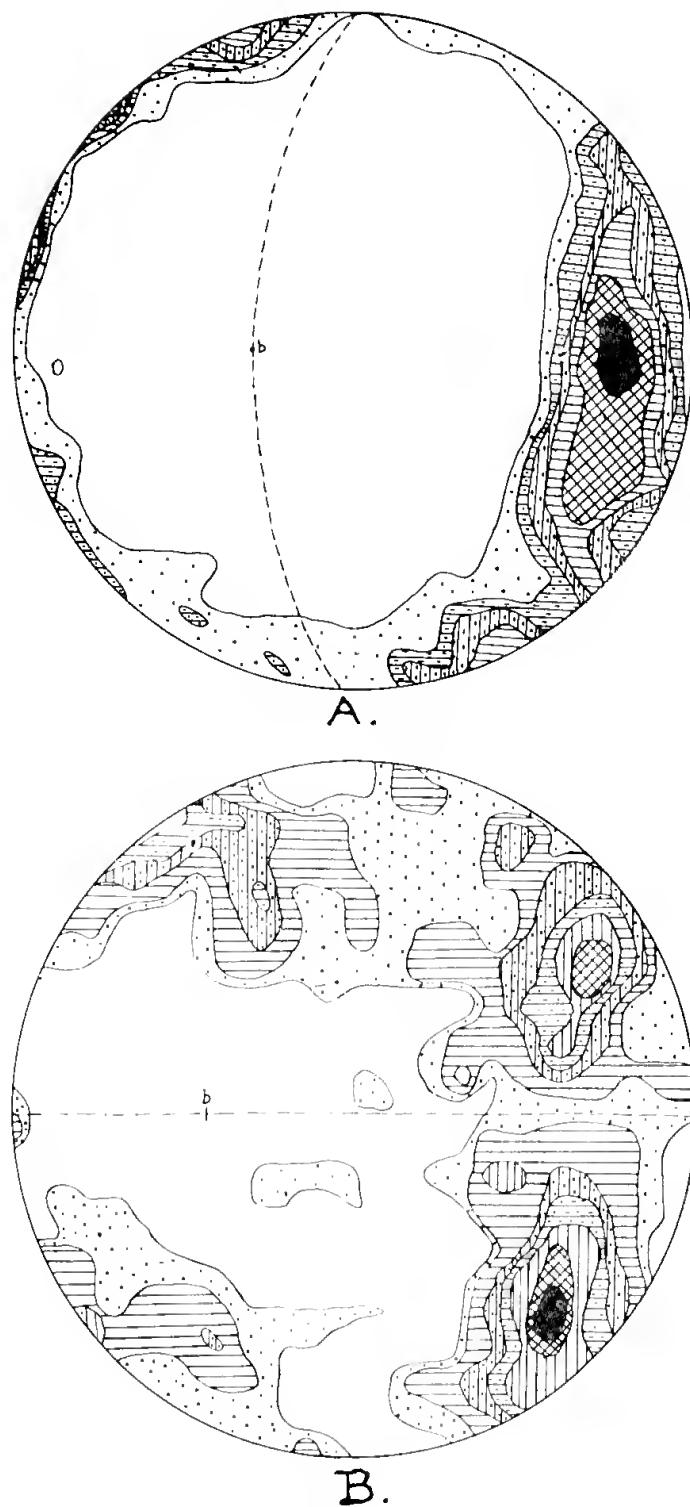


Fig. 5.

Fabric diagrams of the Jimperding quartzites (both rocks cut normal to the b-lineations).

A. Showing rare type of "Trener orientation" (Fairbairn, 1937, p. 70)—a marked elongated maximum coinciding with the "c" fabric axis. Dotted line is plane of foliation. Section perpendicular to marked lineation on bedding plane. Contours 7, 5, 4, 3, 2, 1.

B. Showing normal "ac" girdle with two prominent maxima, equally disposed to the "ab" plane. Dotted line is plane of foliation. Section normal to dip. No lineation apparent in handspecimen. Contours 7, 6, 5, 4, 3, 2, 1.

Complex near Pretoria, are of the opinion that the original purity of the sediment is essential for the formation of very coarse grained types of quartzites. The purity of the very coarse quartzites described above supports this theory.

That these rocks were deformed in an almost plastic state is seen in the minor drag folding which they exhibit—rocks from these dragfolded areas show no more cataclasis than in the less disturbed parts.

It is impossible to recognise any chronological succession in the quartzites as practically all sedimentary features have been obscured by reerystallisation.

(d) *The Fabric of the quartzites and its relation to the geological structure.*—

Fabric analyses have been made of several quartzites, but in the absence of a set of geographically oriented specimens, no conclusions can be drawn from these analyses. They are quoted here to show that the quartzites have a well-marked girdle fabric (*i.e.*, are S-tectonites) and also because one of these rocks (figure 5A) exhibits a rare type of orientation (type "b" of quartz orientation, Fairbairn, 1937, p. 70)—the optic axes are concentrated in a direction normal to the bedding planes (*i.e.*, a prominent maximum lies in the direction of the "c" fabric axis). This maximum is somewhat elongated and spreads out into the typical girdle.

The other analysis (figure 5B) is a more normal type. In it there is a well developed "ac" girdle with two prominent maxima, equally arranged on both sides of the "ab" plane. This is a common type of fabric noted by Phillips (1937) in the Moine Schists of Scotland.

The analyses made, although insufficient to warrant any conclusions, serve to indicate that a fabric study of these rocks would probably yield much information regarding the tectonics of this region. One feature brought out is that the "b" fabric axis in the two analysed specimens coincides with the lineations on the bedding surfaces (*see* figure 2). Although no further fabric analyses have been made, as no universal stage equipment is available in Western Australia (the analyses of the two unoriented specimens described above were made in the laboratory of the Department of Mineralogy and Petrology at Cambridge under the direction of Dr. F. C. Phillips), a re-examination has been made of certain parts of the area with a view to determining the direction and pitch of these "b" lineations which, on the evidence of the two fabric analyses described above, are coincident with the "b" fabric axis (*i.e.*, the tectonic "strike" or tectonic axis, *see* Phillips, 1937, p. 587). These readings are indicated in figure 1, and show that there has been considerable cross folding on the main N.W. trending structure on axes trending N.N.E.

Although this structural study of the Jimperding quartzites is far from complete, sufficient has been done to indicate the desirability of continuing the work when universal stage equipment is available.

(2) *The Calc-Silicate Rocks.*

A rather interesting group of lime silicate rocks occurs in narrow lenticular seams at a constant horizon in the lower quartzites. The rocks lie just below the hornblende schist band and are of rather sporadic occurrence. They are characterised by the presence of grossularite, diopside, pale green amphibole, epidote, and sphene.

The first sign of the presence in the quartzite of lime-magnesia impurities is seen in the development of a pale greenish actinolite along with a little epidote in some felspathic quartzites (*e.g.*, specimen 1250*). Such rocks are

* Numbers are the catalogue numbers in the collection of the Department of Geology, University of Western Australia.

coarse granoblastic structured types in which the amphibole occurs in pale greenish prisms with irregular terminations, either included in the quartz or set between quartz grains. It all has the same orientation and thus tends to give a banded appearance to the rock. Rarely, grossularite is noticed as a constituent of the felspathic quartzites (specimen 1248). Irregular shaped epidote granules and small lozenge shaped idioblasts of sphene are also included in the quartz. In these rocks the (Ca, Mg) silicates are only present as accessories.

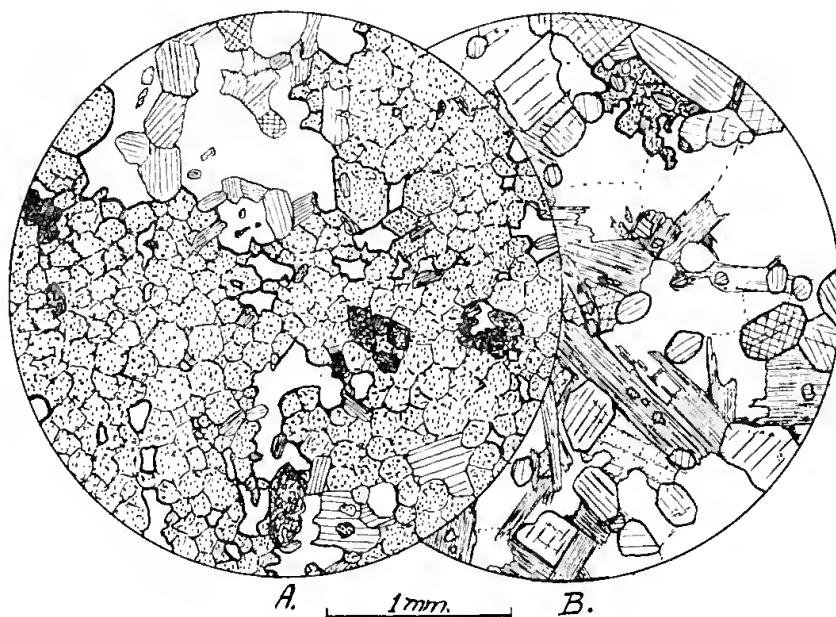


Fig. 6.
Calc-silicate rocks.

A. Quartz-diopside-epidote-grossularite rock (1249), showing grossularite aggregates, with associated sphene, epidote and diopside. The clear areas are quartz xenoblasts.

B. Hornblende-diopside quartzite (15405) with grossularite (at top) and carbonate (centre and bottom).

An increase in the dolomitic impurity in the original sediment leads to the development of several types of rock:—

- (a) Quartz-epidote-diopside-grossular rocks.
- (b) Hornblende-diopside quartzites.

The former type (*e.g.*, specimen 1249) is a fine-grained, massive, pale yellowish, hornfelsic rock with a banded structure, due to the presence of parallel seams and lenses of vitreous quartz, one or two mm. in length. Under the microscope the constituent minerals are:—grossularite, epidote, diopside, quartz, and sphene.

The grossularite is the most abundant constituent forming 60 per cent or more of the rock. It occurs in aggregates of small idioblastic crystals of pale yellow colour. The irregular interspaces are occupied by clear unstrained quartz, towards which the garnet is always idioblastic, also drop-like quartz inclusions are common in the garnet. The garnet is all isotropic and has $N = 1.765$ (by immersion in oils) and is, therefore, a grossularite with slight admixture only of the other garnet molecules.

A pale yellow coloured epidote with very weak pleochroism is fairly abundant, generally in skeletal crystals which, except for the development

of a good 001 cleavage and poorer 100 cleavage, are almost indistinguishable from the grossularite under ordinary light. The refractive index β close to 1.765, extinction $Z \wedge 001$ cleavage = 30° , $\gamma - \alpha$ approximately 0.042 and negative optical character, indicate an epidote with approximately 15 per cent Fe_2O_3 (Winchell, 1933, p. 313). These skeletal crystals often enclose idiomictic grossularite.

Diopsidite is not so abundant. It is a pale greenish variety in hand specimen, colourless in thin section. It occurs in a similar fashion to epidote, enclosing grossularite. The greater part of the diopsidite is confined to the quartzose portions of the rock, where it is idiomictic towards the quartz.

Sphene is an abundant accessory in cloudy irregularly shaped allotriomorphs usually surrounded by garnet. Accessory opaque iron ore occurs in several bands.

Quartz, the only other constituent, occurs in elongated xenoblasts and skeletal grains between the garnet crystals. There are no signs of any strain in the quartz.

The crystalloblastic order is: sphene, grossularite, epidote, diopsidite, and quartz. The microstructures are shown in figure 6A. An analysis of this rock, quoted from Simpson (1937, p. 32) is:—

SiO_2 ...	...	...	...	...	...	50.68
TiO_2 ...	...	...	...	...	...	0.96
Al_2O_3 ...	...	...	...	...	...	12.63
Fe_2O_3 ...	...	...	...	...	...	3.79
FeO ...	...	...	...	...	...	2.13
MnO ...	...	...	...	...	...	1.02
MgO ...	...	...	...	...	...	1.71
CaO ...	...	...	...	...	...	26.81
Alkalies ...	...	...	...	...	...	Tr.
H_2O^+ ...	...	...	...	...	...	0.35
H_2O^- ...	...	...	...	...	...	0.26
						100.34

Judging from its high lime and alumina and absence of alkalies the rock was originally an impure siliceous and argillaceous limestone. The CaO , Al_2O_3 , and SiO_2 have given grossularite, the entrance of some Fe_2O_3 has led to the development of epidote and the CaO with the small amount of MgO has given rise to diopsidite. The source of the titanium of the analysis is sphene, of which there is a small amount in the rock.

The hornblende-diopsidite quartzites are represented by a number of specimens in the collection of which 15405 shows all the characteristic features. Megascopically, it is a coarse-grained, dark green quartzite. Under the microscope, it is essentially a coarse granoblastic aggregate of quartz grains (2-3 mm. diameter) which carry poikiloblastic inclusions of pale greenish diopsidite ($Z \wedge c = 42^\circ$ indicating the presence of some iron) and greenish amphibole. Aggregates of diopsidite, hornblende, grossularite, and a little carbonate occur between the quartz grains. The quartz (70 per cent of the rock) is xenoblastic towards all other constituents. It is all considerably strained and carries minute gas-liquid inclusions.

The amphibole, occurring in pale greenish sheaf-like aggregates, appears to be developing from the diopsidite which is occasionally seen as relicts in the amphibole prisms. The characters of this amphibole are:—

Pleochroism X pale yellow-green; Y deep olive green; Z bluish-green.

The absorption is $Y > Z > X$ and $Z \wedge c = 19^\circ$, indicating that it is blue-green hornblende rather than actinolite.

Grossularite is present in small amount only, in irregular shaped, isotropic, yellow granules, always closely associated with the diopside. There is no epidote in 15405, but it occurs in similar rocks and possesses similar characters to that in specimen 1249 above.

15405 is the only rock in which any carbonate has been noted. It occurs in small xenoblastic forms, always with concave boundaries towards the other constituents. It is most abundantly developed in the vicinity of diopside and hornblende (figure 6B). The complete absence of twinning suggests that it is dolomite rather than calcite.

There can be no doubt that 15405 and related rocks are meta-dolomitic sandstones. Failure of the carbonate to react completely with the silica appears to indicate lack of sufficient aluminous and ferruginous impurities in the original sediment. The co-existence of quartz, grossularite, and calcite (or dolomite) indicates that these rocks have been developed by regional metamorphism under high pressure, for, if thermal metamorphism were responsible, then it would be expected that the remaining carbonate would have reacted with silica to give wollastonite.

The rocks described above are representative of the sparsely distributed calcareous seams in the original sandstones. They undoubtedly represent regionally metamorphosed impure dolomitic sandstones with a varying carbonate content. Kaolinic and ferruginous impurities have led to the formation of epidote and grossularite and a certain amount of iron has entered into the dolomite-quartz reaction producing diopside. In rare instances an insufficiency of impurities has inhibited the dolomite-quartz reaction. The grossularite in these rocks appears to have developed under conditions of regional metamorphism in the sillimanite zone. Tilley (1937, p. 372) has described the development of grossularite under stress conditions in the Loch Tay limestone of Perthshire. Here the grossularite, together with vesuvianite and diopside, first makes its appearance in the Almandine Zone. The Toodyay grossularite rocks show remnants of epidote, which in the Loch Tay limestones appears earlier than grossularite and disappears in the deeper parts of the Almandine Zone. The presence of epidote in the sillimanite zone at Toodyay, along with grossularite, indicates that epidote may, under certain conditions persist through the Almandine Zone.

(3) *The Mica Schists.*

These pelitic members of the Jimperding Series occur at two horizons. In the upper part of the series, a band of mica schist, approximately 250 feet thick, forms the upper limit of the series. This band is characterised by abundant andalusite. Another thinner band near the bottom of the series is characterised by sillimanite. Throughout the whole area the mica schists are considerably weathered, making examination of them somewhat difficult.

The lower mica schist can be traced from the south-east corner of the area almost to the western side. It is interbedded with quartzites and is everywhere contorted by small dragfolds consequent upon its having been folded between the two more competent quartzite beds. In the central part of the area and in the immediate vicinity of the townsite of Toodyay, it is considerably thickened by folding and it has been impossible in this crumpled portion to map all the minor folds.

The following types are developed amongst the mica schists:—

(a) *Sillimanite Schists*.—These are mainly two-mica schists with narrow psammitic bands. Slight variations have been noted and they are illustrated by the following descriptions of typical members:

(i) Quartz-biotite-sillimanite schists (e.g., spec. No. 15638). These are finely schistose structured rocks consisting of bands composed almost entirely of fine acicular sillimanite, alternating with quartz-biotite bands which represent more ferruginous and psammitic layers in the original sediment. The fibrolite bands are occasionally distorted by a later growth of sillimanite in stout cross fractured prisms arranged at about 45° to the schistosity (figure 7A), indicating that a later thermal metamorphism was imposed on the earlier regional metamorphism which had developed the fibrolite. Muscovite (rare) also has a tendency to be arranged with its cleavages at about 45° to the schistosity.

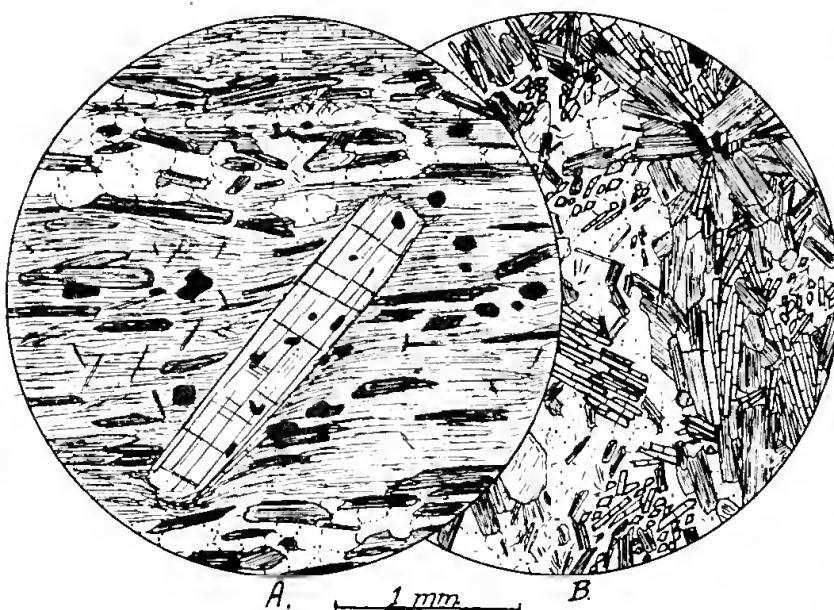


Fig. 7.

A. Sillimanite schist—bands of fibrolite with a little biotite, alternating with quartz-biotite bands. A later growth of sillimanite developed at about 45° to the banding. Note psammitic quartz-biotite bands.

B. Sillimanite-biotite-plagioclase granulite. No tendency to orientation of any constituents. The clear areas are fine granular plagioclase.

The fibrolite appears to be developing from biotite, the iron released in this change being represented by elongated grains of magnetite which occur most abundantly in the fibrolite layers.

(ii) Sillimanite-biotite-plagioclase granulite (e.g., spec. 15678). Such rocks as these show the very interesting association of sillimanite with zoned plagioclase and myrmekite. In hand specimen the rock is fine-grained, greyish in colour with an irregular banded structure—fissile biotite bands alternating with granular quartz felspar bands. Under the microscope the structure is fine, even-grained granoblastic with lenticular areas rich in sillimanite and biotite with schistose structure. The approximate mineralogical

composition is quartz 10 per cent, oligoclase 35 per cent, sillimanite 20 per cent, biotite 30 per cent, muscovite 5 per cent, and accessory magnetite and zircon, but in certain bands the sillimanite content rises to 70 per cent or more of the rock which thus becomes a valuable sillimanite ore.

In the psammitic bands both quartz and oligoclase are xenoblastic. The felspar is invariably zoned, the zoning being reverse gradational in character from $Ab_9 An_1$ centre to $Ab_3 An_1$ periphery; twinning is seen in the central parts but the outer zone is generally untwinned. The outer zones of the plagioclase grains also carry numerous vermicular inclusions of quartz, forming a myrmekite-like structure. The development of this structure in the absence of microcline is interesting—it appears to be due to the growth of the plagioclase around crushed quartz spindles.

The sillimanite is in two generations:—(1) as fine acicular clusters, (2) stout cross fractured rods, the arrangement of which is unusual (figure 7B). In any section they appear to be arranged in bundles, some lying in the plane of the slice, others arranged normal to or at an angle with it.

The biotite is a deep reddish-brown lepidomelane in irregular shaped flakes with but little tendency to parallel orientation. In addition to inclusions of sillimanite there are numerous minute zircon inclusions, surrounded by pleochroic haloes.

Muscovite is in larger plates (1 mm.) carrying poikiloblastic inclusions of quartz and oligoclase. It is penetrated by sillimanite rods but is idioblastic towards the biotite.

Magnetite and zircon are the only accessories.

(iii) Cordierite-sillimanite schists (e.g., specimen 15683). This specimen is the only metasediment of this area in which the presence of cordierite has been noted. There is no sign of schistosity in the rock, either in hand specimen or in the field occurrence. Constituents noted microscopically were quartz, biotite, muscovite, sillimanite, and pinite (after cordierite). The sillimanite is found as small tufts of needles closely associated with a deep reddish-brown biotite and radiating out into the neighbouring quartz. This variety is abundant and appears to be developing at the expense of the biotite. Sillimanite occurs in a second generation, in stouter rods haphazardly included in a pale brownish practically isotropic pinite (after cordierite); in section these pinitic areas measure up to 0.5 mm. diameter. There is no definite orientation in the micas. Plagioclase is absent.

The approximate mineralogical composition is:—biotite 35 per cent, sillimanite 25 per cent, quartz 25 per cent, pinite 10 per cent, muscovite five per cent, and accessory zircon and magnetite.

(b) *Garnet-biotite-plagioclase schist*.—The occurrence of garnet in the mica schists has only been noted in one place (15 chains S., 122 chains W. from datum). Here the garnets are found in a very sandy schistose rock, which, under the microscope, is seen to consist largely of zoned plagioclase. The rock is medium grained, schistose and granular in structure, with porphyroblasts of pink garnet up to 3 mm. diameter. The greater part of the rock consists of an equigranular completely recrystallised aggregate of plagioclase, quartz, and biotite with an imperfect schistose structure due to the subparallel alignment

of biotites. The schistosity is interrupted by the idioblastic garnets which, during their growth, have pushed the biotite flakes aside. The crystalloblastic order is garnet, biotite, plagioclase, and quartz.

The biotite is a strongly pleochroic variety with X pale yellow, $Y = Z$ deep brown, and refractive indices, $\gamma = 1.638$ and $\alpha = 1.591$. Zircon inclusions with pleochroic haloes are abundant. The plagioclase is an albite about Ab_9An_1 and shows slight normal gradational zoning. The centres of some of the crystals are slightly turbid with sericite-epidote alteration products.

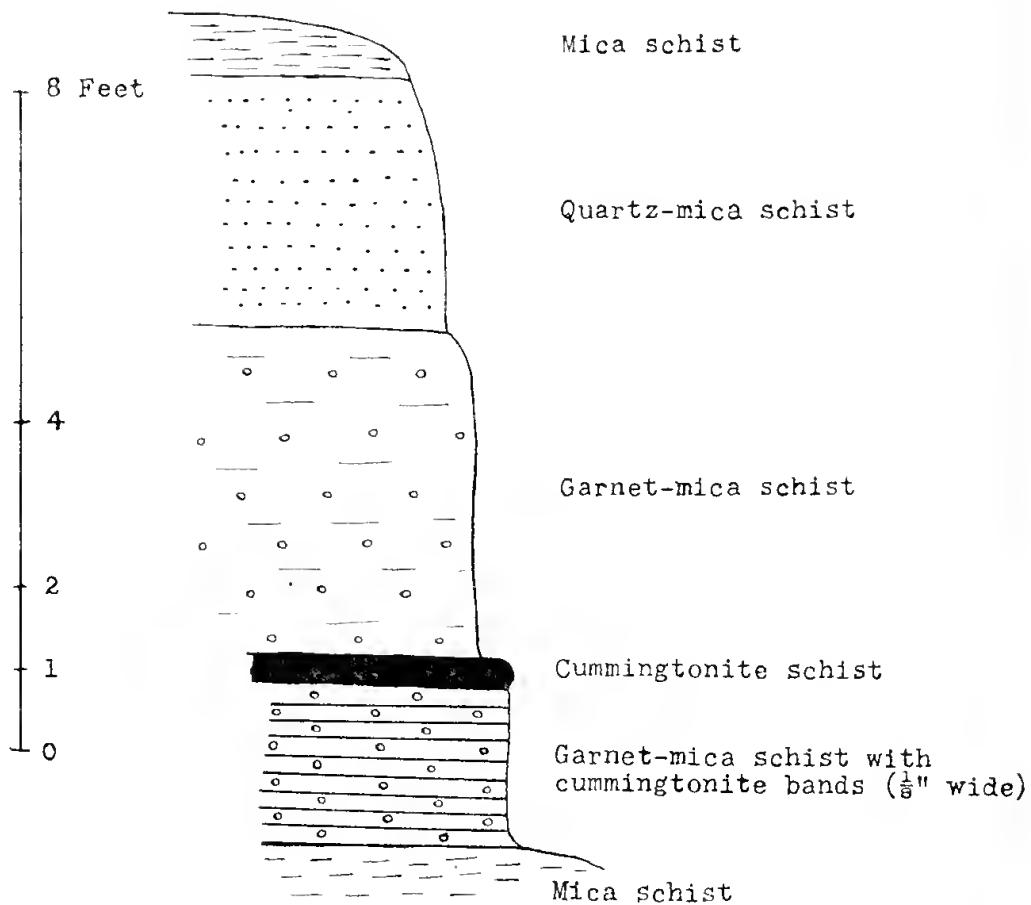


Fig. 8.

Sketch section of small waterfall at the head of Gorge Creek (15 chains S., 122 chains W., from datum), showing the relation of cummingtonite schists to the mica schists.

From the same outcrop as the garnet schist comes:—

(c) *Gedrite-cummingtonite-plagioclase schist*.—A typical specimen (19947) is a pale greenish-grey, fine grained banded rock—light greyish to white bands to $\frac{1}{8}$ in. thick alternating with greenish-grey bands up to $\frac{1}{4}$ in. thick. Under the microscope there is a well-marked schistose structure and the minerals noted were gedrite, cummingtonite, plagioclase, and quartz.

The amphiboles occur in well-shaped prisms (often with poikiloblastic inclusions of plagioclase) up to 1.5 mm. in length. They all lie with their longer axes in the plane of schistosity, but appear to be of random arrangement in these planes since basal and longitudinal sections are present in approximately equal numbers in all sections cut at right angles to the schistosity. Both are pale clove-brown, not noticeably pleochroic varieties and are dis-

tinguishable only by the inclined extinction ($Z \wedge c = 17^\circ$) of the cummingtonite as compared with the straight extinction ($Z = c$) of the gedrite. The former often shows lamellar twinning. The optics of the latter:—

Pale clove-brown, non-pleochroic, $X = a$, $Y = b$, $Z = c$, $(-)$ $2W$ large, $\gamma = 1.667$, $\beta = 1.659$, $\alpha = 1.653$, indicate the aluminous variety, gedrite.

The light-coloured bands are composed of cummingtonite (with gedrite) + plagioclase + quartz, while the darker-coloured bands are much richer in cummingtonite and contain little or no quartz, and in some still darker bands green hornblende becomes an important constituent.

Specimens transitional in character between (b) and (c) are present in the same outcrop (see figure 8), and in these specimens narrow dark bands of garnet-biotite-plagioclase schist (often containing prisms of gedrite) alternate with light-coloured cummingtonite plagioclase rock.

A noticeable feature is that the amphibole in the biotitic bands appears to be all gedrite, whereas this mineral is subordinate to cummingtonite in the lighter-coloured layers.

All the above types (a), (b), and (c) are found in the lower band of mica-schist. They have been derived from argillaceous sediments of variable composition; plagioclase becomes evident in the slightly calcareous bands.

The various associations of sillimanite, biotite, quartz, plagioclase, and cordierite noted above are all well known. The gedrite-cummingtonite-biotite-oligoclase association is much rarer. Amongst the best known comparable rocks are:—

- (1) The gedrite-plagioclaseites of the Kragerö region, Norway, described by Brögger (1935, pp. 213-325). Although generally massive, schistose types have been described from this district. These rocks are considered to be derived from basic igneous rocks in a similar fashion to the gedrite (and anthophyllite)-cordierite rocks.
- (2) The plagioclase-gedrite gneisses of the Nesodden Peninsula near Oslo, described by Brock (1926, p. 180) in which the association "quartz, plagioclase, biotite, garnet, gedrite" agrees very closely with that observed in the Toodyay rock. Brock considers that these rocks have been derived from leptites by addition of FeO and MgO.
- (3) The garnet plagioclase amphibolites of Isopää, Kalliola, Finland, described by Eskola (1936, p. 475). Eskola in this paper describes a paragenesis of gedrite and anthophyllite, an association similar to that noted in the Toodyay schist, and he considers that the gedrite-cummingtonite-garnet amphibolite of Isopää has been formed by metasomatic replacement of basaltic agglomerates.

The gedrite-cummingtonite-biotite-plagioclase schist from Toodyay, from its interlamination with sillimanite schists and the rhythmic banding observed in the specimens appears to be a metasedimentary rock, derived probably from a thin bedded sediment such as an impure dolomitic shale.

(d) *Andalusite schists*.—These are confined to the uppermost pelitic band which outcrops in the S.W. portion of the area. The rocks of this band are quartz-inuscovite schists with a variable biotite content. All the outcrops are highly weathered, the rocks appearing as yellow and reddish iron-stained schists. Simpson (1936, p. 11) has noted the occurrence of sillimanite (fibrolite) in these andalusite schists but it appears to be very rare, as I have noted the presence of sillimanite in one specimen only.

The andalusites show a constant variation in size and number throughout the band as shown in figure 9. At the bottom of the band the andalusites are very abundant—they project from the weathered surfaces forming 40 per cent or more of the exposed surface. The crystals vary in size up to 6 x 2 x 2 ems. The prism (110) is always well developed but the terminal faces are very poorly developed.

Traversing the band towards the south the andalusites become much smaller and less abundant and finally disappear, the rock then being a much weathered reddish muscovite schist which outcrops right up to the granite boundary.

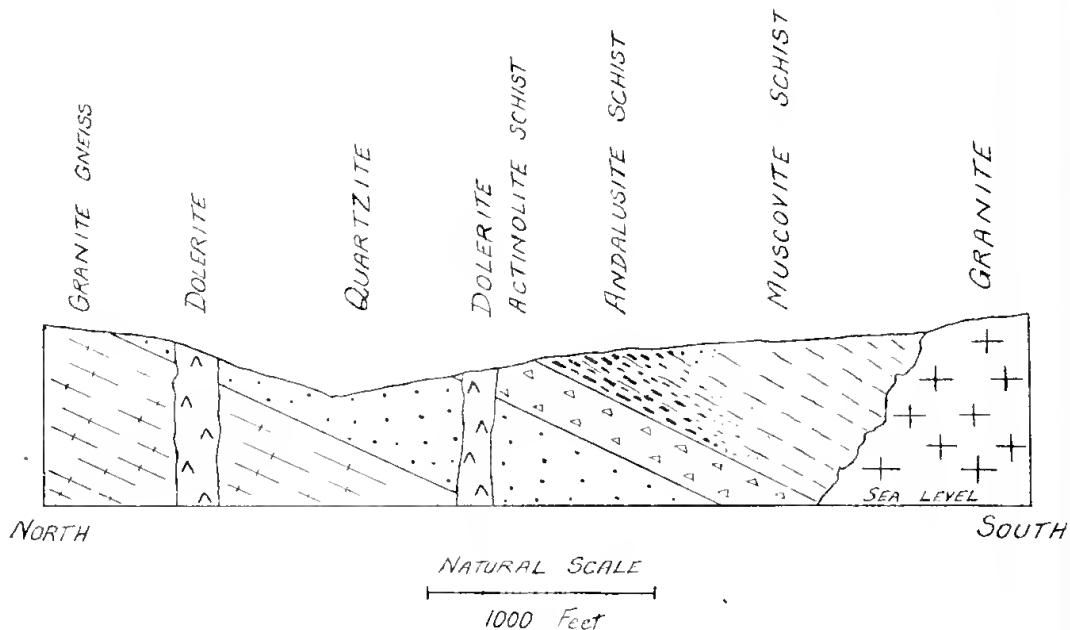


Fig. 9.

Cross section of upper mica schists showing distribution of andalusite.

The andalusites in the lower part of the band, as described and figured by Simpson (1928, p. 50), all show some alteration to muscovite:—

- (1) On the periphery, to a coat of small muscovite plates.
- (2) Within the crystals there is usually an irregular alteration to fine fibrous sericite. Most of the andalusites are clouded with carbon dust inclusions and show the typical chiastolite cross. In addition, we may note a peculiar feature shown by many of these andalusites: the arms and cleavages of the chiastolite cross are curved but the optic orientation remains constant throughout the whole crystal. This feature is similar to that shown by some staurolite and garnet crystals (Harker, 1932, p. 221) due to rotation during their growth.

The groundmass of these rocks is a quartz-biotite-muscovite schist. The biotite is completely weathered. It is interleaved with coarse platy muscovite. Quartz is abundant in smaller irregular shaped grains. Elongated lenses of sericite are common. This material is similar to that developing in the larger andalusites and it appears to result from the shearing out of smaller andalusites in the base of the rock.

In one specimen this sericitic material is present in lenticular areas with irregular inclusions of quartz. The micas are deflected around these knots in a similar manner to the deflection around larger andalusite porphyroblasts.

The only other constituent is rare, well-shaped brownish tourmaline. In one specimen a few stout rods of sillimanite, arranged parallel to the foliation were noted, but this is the only sillimanite present in my specimens.

Proceeding in a southerly direction towards the granite, the andalusites become smaller and eventually disappear. Specimens from this part are similar to the groundmass of the andalusite schist but have a greater abundance of the fine fibrous sericitic bands and knots. Brownish tourmaline is present, but rare. This type of rock persists right up to the granite contact which cuts the schists off abruptly to the south. In a series of specimens collected throughout this band there was no apparent variation in the tourmaline content. The absence of any concentration of this constituent in the schists near the contact seems to negative the possibility that it was introduced from the granite. At the same time its constancy of character indicates a common source for all the tourmaline. Its origin is therefore somewhat doubtful, as it may be developed from constituents introduced from the intrusive granite, or it may be original detrital tourmaline which has been recrystallised.

In considering the origin of the andalusite we naturally look first to the intrusive granite as the source of heat. The granite is intrusive because :—

- (1) It transgresses the bedding of the mica schists.
- (2) Several patches of schists up to 20 chains long x 8 chains wide have been noted which are surrounded by granite.
- (3) It shows no foliation like the granitic rocks in the Jimperding Series.

There has been no apparent thermal alteration of the country rocks. As shown above, the andalusite is absent in the vicinity of the contact and, therefore, the genesis of the andalusite could only be attributed to thermal alteration by the granite if there were an increase in the pelitic constituents of the original sediment as it becomes more distant from the granite. Although no chemical analyses are available, microscopical examination shows that the composition is fairly constant throughout the band, and this rules out the granite as the agent which formed the andalusite.

The granite on its outer margin has suffered no chilling and is just as coarse-grained as it is at a distance of a quarter or half-mile from the contact. This suggests that the intrusion of the granite took place at some depth, into sediments which were themselves in a somewhat heated condition. The possibility of a faulted junction between the granite and schist must, however, not be overlooked.

The distribution of the andalusites indicates an accession of heat from below. There are several intrusive masses, below the andalusite schist (figure 9), which may have supplied the heat necessary for the development of andalusite :—

- (1) The Upper Granitic gneiss.
- (2) An ultrabasic sill now represented by a monomineralic actinolite schist.
- (3) Dolerite dykes. These could not have effected the development of andalusite as they are post granite in age, whereas the development of andalusite was pre-granite.

Later retrogressive changes in the andalusite (*i.e.*, replacement by muscovite and sericite) are probably due to pneumatolytic alteration by vapours from the intrusive granite to the south, in a similar manner to the alteration of sillimanite to muscovite noted by Simpson at Clackline (Simpson, 1936,

p. 13). In addition there has been a considerable amount of shearing after the formation of andalusite, which in specimen 16743 is cracked and sheared out into lenticles consisting mainly of sericite but carrying reliefs of andalusite.

(4) *Hornblende schists* (plagioclase amphibolites).

There are several different modes of occurrence of these rocks:—

- (1) as well defined bands (average thickness 40 feet), interbedded with quartzites. All have been completely recrystallised and variable grain features, which may indicate the original nature of the mass (Cooke, etc., 1931, p. 49) have been obscured. These bands never transgress the bedding of the associated sediments, and they appear, in view of the great area over which they retain their constancy of character and horizon, to be basaltic flows which have been folded along with the associated sediments.
- (2) as irregular shaped inclusions, usually of small areal extent, in the upper granitic gneiss. These are considered to be xenolithic bodies.
- (3) coarser-grained xenoliths in the lower granitic gneiss. These are often veined with granitic material.

The two latter occurrences will be considered later in a section dealing with the xenoliths in the gneiss.

The schistose plagioclase amphibolites interbedded with the metasedimentary rocks are remarkably constant in character, consisting mainly of blue-green hornblende and acid plagioclase, with minor amounts of epidote, quartz, microcline, magnetite, sphene and apatite. The only variants of this type are diopside-plagioclase amphibolites of rather rare occurrence.

15437 is a typical example of the normal hornblende schist. It is a medium grained schistose rock consisting predominantly of hornblende. Epidote is an abundant constituent, and in hand specimen is seen to occur in pale yellow-green seams running parallel to the schistosity.

Under the microscope the rock has a well defined schistose structure, the hornblende occurring in irregular shaped prisms (average 0.5-mm. long), in parallel alignment. Other constituents are plagioclase, microcline, epidote, quartz, and sphene.

The hornblende prisms often carry small poikiloblastic inclusions of quartz and felspar. The hornblende is a common blue-green variety with X yellow to yellow-green; Y olive to brownish-green; Z bluish-green, and absorption $X < Z < Y$, $\beta = 1.672$ and $Z \wedge c = 20^\circ$.

The epidote is the pale yellow highly birefringent pistachite, usually confined to narrow bands parallel to the foliation. In the vicinity of epidote the hornblende is represented by a pale greenish bleached variety. Along joint cracks which are not coated with epidote the hornblende is also bleached—such joints traverse the hornblende crystals without dislocating them and are only evidenced by the presence of a narrow seam of more fibrous bleached hornblende which has the same optical orientation as the crystal traversed. There has clearly been some transport of material along these microscopical fractures, as seen by the occurrence of the same pale amphibole along the joint plane where it traverses quartz and felspar grains.

Two varieties of felspar are present, both xenoblastic and slightly elongated parallel to the schistosity. Albite, which is slightly turbid with fine granular epidotite and fibrous sericitic alteration, is most abundant. It rarely shows lamellar twinning, is not zoned, and its refractive index $\gamma \lesssim 1.54$ indicates an albite with less than 10 per cent An.

The less abundant microcline is all water-clear and shows the characteristic cross hatched twinning. Microcline although rarely present in amounts exceeding 5 per cent is a constant constituent of these rocks.

The only accessory is sphene, in small imperfect crystals usually enclosed by hornblende.

This rock has been analysed as typical of these hornblende schists (Table 1, col. 1). It is an analysis closely resembling that of igneous rocks of the composition of quartz dolerite. An analysis of a dolerite from this area appears in column 4.

TABLE 1.

Analyses of Basic Rocks from the Toodyay Area.

		1.	2.	3.	4.
SiO ₂	...	53.61	50.20	49.05	49.13
Al ₂ O ₃	...	10.77	15.00	15.03	13.13
Fe ₂ O ₃	...	2.21	3.83	3.16	3.65
FeO	...	9.02	8.93	9.08	8.95
MgO	...	6.92	6.04	6.96	7.64
CaO	...	10.04	10.65	10.47	11.84
Na ₂ O	...	2.12	1.90	1.70	1.72
K ₂ O	...	1.54	0.07	0.95	0.16
H ₂ O+	...	1.62	1.62	1.43	1.72
H ₂ O-	...	0.17	0.07	0.25	0.04
TiO ₂	...	1.05	1.06	1.07	1.27
P ₂ O ₅	...	0.17	0.12	0.08	0.14
MnO	...	0.35	0.16	0.09	0.15
FeS ₂	...	n.d.	n.d.	0.13	0.45
		99.59	99.65	99.45	99.99
<i>Norms.</i>					
Q	...	5.10	6.18	1.98	3.48
Or	...	8.90	0.56	5.56	1.11
Ab	...	17.82	16.24	14.15	14.15
An	...	15.57	31.97	30.58	27.52
di	...	27.30	16.41	16.68	24.88
hy	...	17.52	19.18	21.58	18.33
mg	...	3.25	5.57	4.64	5.34
il	...	1.98	2.13	2.13	2.43
ap	...	0.34	0.34	0.34	0.34
py	...	—	—	0.13	0.45

1. Schistose plagioclase amphibolite (15437), interbedded with quartzite, Toodyay, W.A.
2. Schistose plagioclase amphibolite (1241), xenolith in Upper granite gneiss, Toodyay, W.A.
3. Coarse granular quartz-plagioclase amphibolite (15441), xenolith in Lower granite gneiss, Toodyay, W.A.
4. Quartz dolerite (15424), dyke in metamorphic rocks, Toodyay, W.A.

All analyses by R. T. Prider.

Amongst the rocks forming this band there is, as previously noted, but little variation. Microcline may be absent and quartz may be more abundant than in the type rock. Iron ore rimmed with sphene, indicating its origin from ilmenite, is a common feature, although in the rock described above the usual central ore inclusion in the sphene is absent.

The most unusual variant of the plagioclase amphibolites is a type in which diopside finds considerable development. 15440 is typical—it appears in hand specimen to be a normal hornblende schist with narrow bands and lenticles (never more than 2 mm. wide) of light greenish diopside.

Under the microscope the constituents are hornblende, diopside, and plagioclase with accessory quartz, apatite, and sphene. The hornblende and diopside are concentrated into alternate bands (figure 10B) and appear to have crystallised independently. The hornblende has a much stronger absorption than that described above—it has X yellow-green; Y brownish-green; Z deep bluish-green; and absorption $X < Z \lesssim Y$; $\beta = 1.674$; and $Z \wedge c = 16^\circ$. The diopside is in irregular equidimensional grains to 0.5 mm. diameter. They have no definite orientation, the longitudinal cleavage being arranged at various angles to the schistosity, indeed often normal to it. This mineral is a pale greenish variety with the (110) cleavage well developed, $Z \wedge c = 42^\circ$, indicating the considerable iron content. The diopside is idioblastic towards both the plagioclase and hornblende. Plagioclase forms

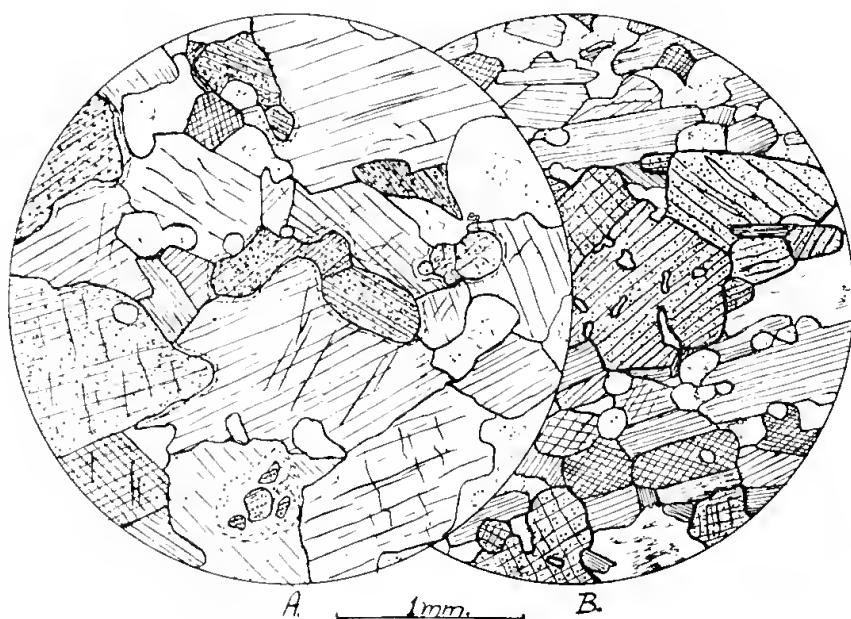


Fig. 10.

Pyroxene-plagioclase amphibolites.

A. Coarse xenolith in Lower Gneiss. Constituents: diopside (dotted), hornblende (paler coloured at junction with diopside), slightly turbid plagioclase, quartz.

B. Fine banded variety interbedded with quartzite. Constituents: hornblende in well defined bands, diopside (dotted), plagioclase.

approximately 30 per cent—it appears in two generations (1) a very turbid indeterminable variety clouded with secondary fine granular zoisite—this variety is more or less confined to the hornblende bands; (2) a clear fresh plagioclase associated with the diopside bands. Fine lamellar twinning is occasionally developed and the small extinction ($2^\circ - 3^\circ$) in sections $\perp 010$ indicates an oligoclase. Slight normal gradational zoning is noticeable in some grains.

Sphene and rare apatite are the only accessories. Iron ores are absent.

Another specimen belonging to this group has an "augen" structure—the augen are of diopside aggregates set in a plagioclase amphibolite ground in which the felspar is heavily saussuritised.

A specimen taken from the upper contact of the hornblende schist with the quartzite at a point 132 chains E. and 229 chains S. of datum, shows a

gradation from normal plagioclase amphibolite, through epidotite to a diopside-plagioclase rock in which grossularite is present in small amount—this latter type is developed right at the contact.

The plagioclase amphibolite portion of the specimen is the normal type in which the felspar is very turbid with fine granular epidote. Following this is a narrow band ($\frac{1}{4}$ inch) consisting predominantly of yellow epidote (pistachite) with a minor amount of pale greenish hornblende and quartz—the hornblende then decreases in amount leaving an almost pure epidote band ($\frac{1}{4}$ inch) in which lozenge shaped sphene are a notable constituent. In the outer part of this band grossularite is occasionally seen. Beyond this, the rock consists of epidote, slightly turbid plagioclase (Ab_9An_1) and quartz, the two latter occurring in micrographic intergrowth. On the outer limit of the specimen, the rock consists of diopside and saussuritised plagioclase with a little grossularite, sphene, and quartz. Were it not so clearly related to the plagioclase amphibolite, such a rock could conceivably have resulted from the metamorphism of an impure argillaceous limestone. The development of grossularite in this rock is interesting, as it has developed from the epidotic alteration of the original felspar.

The main features which elucidate the origin of these schistose plagioclase amphibolites are:—

- (1) They occur interbedded with metasediments and never transgress the bedding.
- (2) They are constant in character throughout the area. Rarely, more calcic diopside layers alternate regularly with layers of the normal amphibolite. A similar feature to this is seen in the Landewednack hornblende schists of the Lizard, Cornwall (Flett and Hill, 1912, p. 46).
- (3) The refractive index ($\beta = 1.673$) of the hornblende is indicative of hornblendes from epidiorites in the sillimanite zone (Wiseman, 1934, p. 394).
- (4) In their chemical composition they are normal igneous rocks, such as would result from the crystallisation of a quartz dolerite magma.

These plagioclase amphibolites appear, therefore, to be metabasic igneous rocks, which formed either a sill or flow in the metasediments prior to the orogenic period, and have been folded along with the metasediments. In view of the complete recrystallisation, no evidence is available as to whether these were originally flows or sills.

(5) *The Granite Gneisses and the associated xenoliths.*

As described above, there are two bands of light coloured granitic gneiss developed in the area. The Upper and Lower Gneisses form bands estimated to be approximately 2,000 feet and 5,400 feet thick respectively. Mineralogically, there is but little difference between the two, although the upper band, in view of the greater abundance of microcline is somewhat the richer in potash. It has also suffered more crushing than the Lower Gneiss and is everywhere a typical augen gneiss with large "eyes" of microcline, surrounded by a granular quartz-biotite-microcline aggregate. The lower gneiss is essentially a fluxion gneiss, in many places a coarse porphyritic type with idiomorphic microcline phenocrysts (up to 1 inch long), which have a linear orientation due to flowage. Both gneisses are penetrated by late stage pegmatitic products of the granitic magma—these may be narrow sills or veinlets traversing the foliation, usually only a few inches wide.

The Upper Gneiss is constant in composition and structure throughout. In places the crushing has been so complete as to obliterate the augen structure and fine banded gneisses have resulted. Such rocks have elongated narrow lenticles rich in fine granulated microcline, alternating with long sill-like streaks of unstrained quartz, in which the quartz extinguishes as a unit.

The foliation in both bands conforms to that in the associated metasediments. In the case of the upper gneiss, the gneiss-quartzite contact is often a narrow crush zone, varying from a few inches to a few yards in width. The rocks of this zone are quartz-sericite schists, in which the quartz appears in elongated lenticles up to $1\frac{1}{2}$ inches x $\frac{1}{4}$ inch x $\frac{1}{8}$ inch with prominent cross fractures (tension joints)—these lenticles are elongated in the plane of foliation, but more elongated parallel to the strike than to the dip.

In both gneisses there is often an irregular folding and contortion of the flow layers rich in biotite, due to folding movements which were taking place contemporaneously with the flowage.

That the gneisses are of igneous origin cannot be doubted in the evidence presented by numerous xenolithic bodies of variable composition—some metasediments, others metabasic igneous. These will be described presently. In places at the bottom of the Upper Gneiss (notably in Poison Creek), the gneiss is discordant to the bedding in the quartzite and small offshoots traverse the bedding of the quartzite.

We will consider firstly the Upper Granitic Gneiss and its associated xenoliths.

(a) *The Upper Granitic Gneiss.*

The main characteristics may be summarised thus:—

- (1) Augen gneissic structure is characteristic throughout.
- (2) Ptygmatic folding is occasionally developed.
- (3) With the exception of occasional small basic xenoliths, narrow lenticles of plagioclase amphibolite and irregular small biotite granulite xenoliths, the composition is fairly constant throughout.
- (4) Microcline is the dominant felspar.
- (5) Myrmekitic structures are developed in most types.
- (6) Biotite is invariably chloritised and contains saganitic rutile inclusions.
- (7) Narrow veins of pegmatite and aplite are numerous.
- (8) Garnet and the various aluminium silicates characteristic of metasediments are completely absent.

The main type of the Upper Gneiss is a microcline granite gneiss, but other minor types are occasionally noticed. The varieties of Upper Gneiss are:—

- (i) *Biotite-microcline granite gneiss.*—These are medium-grained rocks with augen gneissic structure. The augen are of microcline up to 1 cm. x $0\cdot5$ cm., in an even-grained ground of quartz, felspar, and biotite, the latter in sub-parallel alignment. The quartz is in elongated ellipsoidal grains (5 mm. x 3 mm. x 1 mm.) showing greatest elongation parallel to the strike and lesser parallel to the dip.

Under the microscope the minerals observed were quartz, microcline, oligoclase, and biotite with accessory magnetite, apatite, muscovite, zircon, epidote, rutile, and myrmekite.

Microcline is most abundant, occurring in xenoblastic plates, usually, but not always showing peripheral granulation (Plate III, C). This

granular microcline aggregate is comparatively coarse-grained and seems to be a protoclastic, rather than a cataclastic structure—this is supported by the absence of any cataclasis or marked strain in the associated quartz. The microcline may carry small inclusions of quartz and plagioclase, and in the latter instance myrmekitic intergrowths of quartz with the plagioclase are usually present.

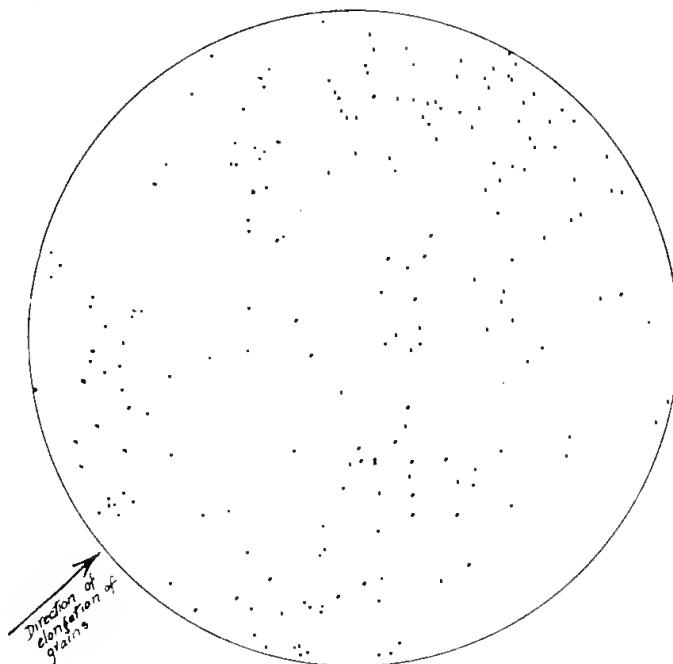


Fig. 11.

Fabrie diagram of Upper granite gneiss. Plot of poles of optic axes of 200 quartz grains, showing the complete absence of any orientation in the quartz.

The quartz is in irregular shaped unstrained grains forming a constituent of the microcline mosaic and, as allotriomorphs, elongated parallel to the gneissic banding (Plate II, A and B, and Plate III, D), in which case it often includes parallel aligned biotite flakes. The quartz shows slight undulatory extinction but has not suffered any granulation and has been either:—

- (1) of post tectonic crystallisation : or
- (2) original crushed grains, completely recrystallised into elongated xenoblastic forms.

A fabric analysis was made of a fine even-grained granitic gneiss, showing this marked elongation of unstrained quartz grains, but after the measurement of 200 grains no apparent concentration of the optic axes in any direction was noticeable (figure 11). Similar results were obtained from several other granite gneisses which were analysed.

It is interesting to compare this result with those obtained for several of the quartzites (figure 5. A and B), which show such a well-marked fabric. It would be expected that the gneiss would possess a fabric similar to the quartzites. The complete absence of any girdle in the diagram for the gneiss indicates that the quartz is of post tectonic crystallisation. This is verified by the observation, in some rocks, of granular microcline inosomites included in the quartz.

Plagioclase (10 to 15 per cent) is generally a slightly turbid and poorly twinned oligo-albite (Ab_9An_1) which is partly replaced by myrmekite when in contact with microcline—it is never zoned, and is invariably replaced in part by fine fibrous sericite.

Biotite which, on the average, forms 10 per cent of these rocks is of two types—(1) A strongly pleochroic greenish brown variety with minute sagenitic rutile inclusions. The flakes are well formed parallel to 001 , but have ragged terminations. It is partially replaced by green chlorite, especially along the cleavage, leading to an intergrowth of these two minerals. (2) A bright greenish completely chloritised biotite, usually developed in contact with microcline and intergrown with epidote. The biotites often occur in small clustered aggregates—in the more crushed varieties they occur in well defined bands, curving around the lenticular granulated microcline aggregates.

Apatite is the most abundant accessory in stout idiomorphic prisms. Minor accessories are small zircons (with weakly pleochroic haloes) included in biotite, scattered grains of magnetite and epidote.

Specimen No. 1213, an even-grained type, has been analysed as typical of these granite gneisses, and the analysis appears in Table 2, Column 1. It is a typical granite, and the appearance of a little corundum in the norm is due to the slight secondary alteration of the felspars. There is insufficient excess alumina to suggest the possibility of a sedimentary origin for these gneisses. (Bastin, 1909, p. 461.)

TABLE 2.

Granite Gneisses from the Toodyay Area.

				1.	2.
SiO_2 ...	...	...	...	71.85	63.28
TiO_2 ...	...	...	...	0.25	0.83
Al_2O_3 ...	...	...	...	15.00	14.56
Fe_2O_3 ...	...	...	...	0.55	3.13
FeO ...	...	...	...	1.20	5.10
MnO ...	...	...	...	Tr.	0.09
MgO ...	...	...	...	0.42	1.70
CaO ...	...	...	...	1.52	3.51
Na_2O ...	...	...	...	3.67	3.66
K_2O ...	...	...	...	4.45	2.58
H_2O+ ...	...	...	...	0.54	0.52
H_2O^- ...	...	...	...	0.02	0.15
P_2O_5 ...	...	...	...	0.11	0.45
				99.58	99.56
<i>Norms.</i>					
Q ...	...	...	...	29.52	20.40
Or ...	...	...	...	26.13	15.57
Ab ...	...	...	...	30.92	30.92
An ...	...	...	...	6.67	15.01
C ...	...	...	...	1.73	0.20
hy ...	...	...	...	2.58	9.74
mg ...	...	...	...	0.70	4.41
il ...	...	...	...	0.30	1.52
ap ...	...	...	...	0.34	1.01

1. Biotite-microcline granite gneiss (Spec. 1213), Toodyay, W.A. Analyst, R. T. Prider.
2. Biotite-oligooclase granite gneiss (Spec. 15389), Toodyay, W.A. Analyst, R. T. Prider.

(ii) *Microcline-granite gneiss*.—The mica is much less abundant than in type (i). These rocks are rare and occur in narrow seams. They consist essentially of microcline, quartz, plagioclase, and accessory biotite, and, therefore, probably represent an originally aplitic phase of the granite. The microcline is slightly microperthitic, and the less abundant plagioclase is a clear, finely-twinned oligoclase ($Ab_{85}An_{15}$). Such mica as is present is the same greenish-brown partially chloritised variety as described above.

(iii) *Biotite-oligoclase-granite gneiss*.—In this type, which is of rare occurrence, there is a much greater development of brownish biotite than in (i) above. The main felspar is oligoclase, and microcline is present to the extent of less than 10 per cent. The approximate mineralogical composition of a typical specimen (9577) is—

Quartz	....	....	....	20 % by volume
Oligoclase (Ab_4An_1)	....	....	....	65 %
Microcline	....	....	....	5 %
Biotite	....	....	....	10 %

Accessory rutile, zircon, and apatite.

The oligoclase is in subhedral crystals averaging 2 mm. diameter, with oscillatory normal zoning and average composition Ab_4An_1 . Occasional plates of microcline are present and, when in contact with oligoclase, myrmecite is developed.

The biotite is a brownish, non-chloritised variety, but still carries the characteristic sagenitic rutile inclusions.

(b) *Xenoliths in the Upper Granitic Gneiss*.

(i) *Schistose plagioclase amphibolites*.—These are found in narrow irregular bands, varying from small stringers, several inches wide, which taper out quickly, to well-defined bands up to one chain wide which usually run parallel to the foliation of the gneiss. The occurrence in them of acid veinlets suggests that they are inclusions, rather than sheet-like intrusions, in the gneiss, and they often show a minute crumpling which accords with the view that they are xenolithic, rather than post gneiss intrusions, as there have been no major tectonic movements since the final consolidation of the granite gneiss.

There is little variation in these rocks and they are almost identical, both mineralogically and chemically, with the plagioclase amphibolites, already described, which occur interleaved with the meta-sediments. The main points of difference may be summarised :—

- (1) Xenoliths in the gneiss have hornblende with a much stronger pleochroism :—X yellow-green ; Y deep olive green ; Z deep bluish-green ; and absorption $Y \geq Z > X$.
- (2) The plagioclase is more saussuritised and less abundant in the xenoliths.
- (3) Microcline is absent from the xenoliths and quartz more abundant.
- (4) Magnetite, rimmed with sphene, spread out into trains parallel to the schistosity, is more abundant in the xenoliths.

A specimen of contorted hornblende schist (No. 1241) from a xenolith in the granite gneiss was analysed and the result is seen in Table 1, Column 2. The main points of difference from the previously described hornblende schists lie in the lower SiO_2 and corresponding higher alumina in the xenolith. The

alkalies, especially potash, are also slightly lower. These features indicate the close resemblance of the two rocks and also indicate that there has been no addition of material to the xenoliths from the granite gneiss.

(ii) *Hornblendic schlieren*.—These small lenses in the upper gneiss were only noted in one place (40 chains N., 527 chains W. from datum). They are irregular shaped lenticles up to 12 inches wide, which are elongated parallel to the foliation of the enclosing gneiss.

That these schlieren are older than the intrusive granite gneiss is shown by the narrow granitic veinlets penetrating them, and also by the fact that small fragments of the xenolithic material are found in the enclosing gneiss.

The central portion of these inclusions is made up largely of a dark green, bladed hornblende, in crystals up to 0.5 cm. long, with occasional larger plates of a pale greenish pyroxene. Small white angular patches and veinlets of felspathic material are present. Near the edge of the xenoliths the rock becomes lighter in colour, hornblende becomes rarer, a pale greenish pyroxene taking its place. The enclosing gneiss is a fine granulitic microcline granite gneiss.

Under the microscope the fine microcline gneiss is seen to have pale greenish hornblende derived from the hornblendic xenolith, as its ferromagnesian. Approaching the contact the most noticeable features are (1) the increase in the hornblende content, (2) entrance of idioblastic sphene and colourless pyroxene, (3) decrease of microcline and corresponding increase of oligoclase. The felspars at the actual contact are considerably epidotised.

The xenolith itself is made up mainly of pyroxene, hornblende, and introduced quartz-oligooclase veinlets. The outer zone of the xenolith is rich in pyroxene (in large plates up to 4 or 5 mm. diameter), which under the microscope are seen to be fringed with pale greenish hornblende. The pyroxene in thin section is colourless, with 110 cleavages well developed and a marked parting parallel to 100 and less perfect parting on 010.

The properties $Z \wedge e = 42^\circ$; $\gamma = 1.705$; $a = 1.676$; $\gamma - a = .029$; biaxial (+), and very weak dispersion, point to a diopsidic pyroxene with 20 per cent. of the hedenbergite molecule.

The amphibole which is clearly developing from the pyroxene is a pale greenish, somewhat fibrous variety, with an irregular coloration in the same crystal. Pleochroism is X yellow-green; Y olive green; Z bluish-green; and absorption X < Z < Y. $Z \wedge e = 23^\circ$. This is a common blue-green hornblende. It is usually developed where the pyroxene is in contact with oligoclase and rarely where in contact with quartz, the hornblende having apparently obtained its alumina from the felspar.

In the centre of the xenolith, although most of the diopside has been replaced by amphibole, cores of diopside in this mineral point clearly to its origin.

These xenoliths have been originally diopsidic rocks, now converted into rocks composed predominantly of hornblende. An anomalous feature is that the cores show considerably more alteration than the periphery. There has been a slight hybridisation of the adjoining granite (gneiss) giving rise to a fine-grained hornblende granite gneiss. This hybridisation of the granite is developed on a larger scale in the Lower Gneiss and this question will be considered more fully at a later stage.

(iii) *Biotite granulite xenoliths*.—These are much finer-grained and carry more ferromagnesians than the enclosing gneiss, in which they occur as irregular shaped elongated darker-coloured patches, in which the foliation approximates to that in the surrounding gneiss. All these rocks are alike

petrologically, being composed of partly chloritised biotite, quartz, and oligoclase with accessory magnetite, apatite, and sphene. One specimen, however, shows a development of a deeply-coloured hornblende.

The boundaries of the xenoliths are sharp and there is no transitional hybrid zone. The structure is fine, even granular, schistose (figure 12). The plagioclase carries minute rodlike inclusions of recrystallised muscovite. It is rarely twinned but its refractive index, approximately equal to that of Canada balsam, indicates that it is an oligoclase.

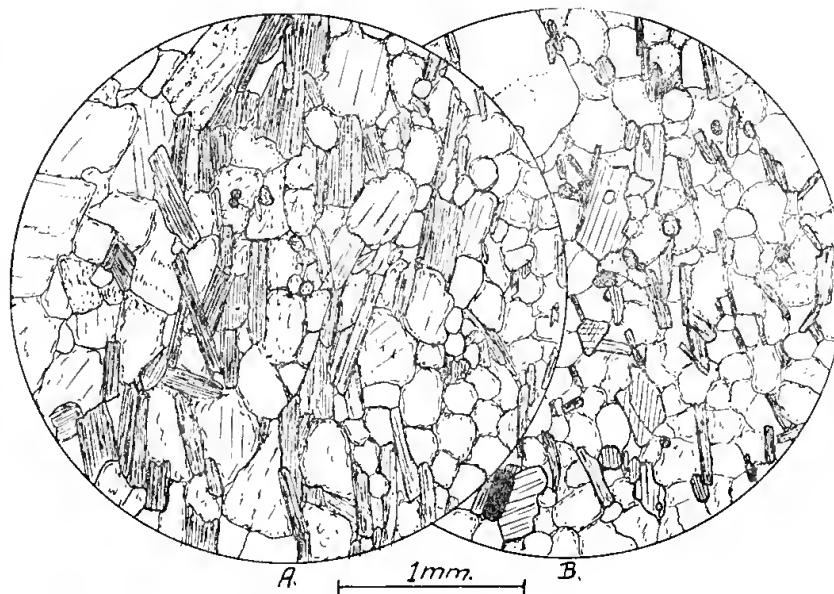


Fig. 12.

Biotite-quartz-plagioclase granulite xenoliths in granite gneiss.

A. No. 1220. Edge of xenolith. The left hand edge of the field is occupied by the coarse granite gneiss, the right hand portion by the biotite-quartz-plagioclase granulite.

B. No. 1221. Variety with deep greenish hornblende.

The biotite is a greenish-brown variety, altered along cleavages to chlorite.

The deep green hornblende present in one of these rocks tends to occur in small elongated, often enclosing magnetite.

Accessories are apatite, magnetite, epidote, and sphene.

These rocks represent psammitic types of sediments, which with the admixture of a little calcareous material have at times developed hornblende and epidote; they cannot be matched with any of the metasedimentary rocks in the Jimperding Series.

(iv) *Eulysitic rocks* (meta-banded ironstones).—Banded quartz-magnetite-grunerite rocks with affinities to the eulysites have been noted as enclosures in the Upper Gneiss in two places: (a) At 26 chains E., 40 chains N. of datum. This occurrence is in the form of a band, several chains wide, which can be traced for about 30 chains in a south-easterly direction. (b) At 92 chains W., 140 chains N. of datum. This occurrence is also a band in the gneiss, about 1 chain wide and can be traced for about 30 chains in a north-easterly direction. Both of these bands lie close to the bottom of the Upper Gneiss and are probably both part of the same horizon. The rocks from both occurrences are essentially the same, being magnetic banded rocks composed of varying

proportions of quartz, magnetite, and grunerite. These rocks are similar to some occurring as xenoliths in the Lower Gneiss, which are described in a later section ((5) (e) (i)) of this paper.

(c) *Summary of Conclusions regarding the Origin of the Upper Gneiss.*

The main mass is constant throughout and is a normal biotite-microcline augen gneiss, derived from a porphyritic microcline granite. The presence of both sedimentary and igneous xenoliths and the occurrence of small transgressive apophyses in the underlying quartzite, point clearly to its intrusive character.

The gneissic banding was developed when the rocks had partially crystallised (*i.e.*, it is a fluxional foliation due to the alignment of the microcline), during which time protoclastic structures were developed. The final crystallisation of quartz took place after the tectonic movements had ceased.

The microcline granite was intruded as a thick sill which has produced no apparent thermal effects in the associated sediments which are in every instance quartzites. Such rocks, however, would not be expected to yield any information regarding the degree of thermal metamorphism induced by the granite. Felspathisation of quartzose rocks, about which a good deal has been written, is not developed in the Toodyay Area. It is not clear why the quartzites above this gneiss have different microstructures from those below the gneiss. If the granite were a sill we should expect them to be identical.

(d) *The Lower Granite Gneisses.*

These rocks, outcropping in the north and north-east parts of the area, vary from fine, even-grained, well-banded types, to coarse porphyritic granites in which the banding is visible only in a flow orientation of the microcline phenocrysts.

The well-banded varieties all have granoblastic structure with but little sign of granulation. A gneissic structure is evident in the sub-parallel orientation of the biotite and in the elongation of the felspar and quartz allotropic morphs in a common direction. In these finer-grained gneisses the quartz grains have an average index of elongation of about 3 : 1.

The mineralogical composition of the Lower Gneisses is fairly constant, irrespective of whether the rock is fine-grained or coarse porphyritic. The average composition by volume is :—

Oligoclase (Ab ₄ An ₁)	...	...	...	30%
Microcline (slightly micoperthitic)	...	...	...	30%
Quartz	...	...	...	30%
Biotite	...	...	...	10%

with accessory apatite, magnetite, and more rarely sphene and epidote.

Minor variations due to a greater abundance of biotite together with an increase of the proportion of oligoclase to microcline (as in the Upper Gneiss) have been noted. Also a hornblende bearing granite gneiss is developed by hybridisation of the granite by the hornblende xenoliths which are present in some abundance.

The main point of difference from the Upper Gneiss lies in the general absence of cataclastic (or protoclastic) structures.

The microcline phenocrysts which in the Upper Gneiss are represented by lenticular "eyes" are here seen to be well-shaped, uncrushed crystals (up to 1 inch in length).

Biotite-oligooclase gneisses similar to those in the Upper Gneiss have been noted in narrow bands. Spec. No. 15389 is a type containing approximately 25 per cent. of a brownish biotite. It has been analysed as typical of these rocks (Table 2, No. 2). It differs from the microcline bearing gneiss in its higher iron and lower silica and potash content.

Under the microscope, oligoclase in subhedral grains up to 4 or 5 mm. diameter is the dominant constituent. It shows fine albite twinning, the lamellae often being slightly curved due to strain. A noticeable feature is that the quartz moulded on such a strained crystal shows no undulose extinction. The brownish biotite is in flaky aggregates winding around the larger oligoclases; they feather out against one another and have been squeezed together by movements in the semi-crystallised magma. The microstructures recall in many ways the "round grained" gneisses of Glen Doll, Forfarshire (Harker, 1932, p. 298).

Apatite is a very abundant accessory, in small stout prisms, closely associated with the biotite rich bands.

These biotite-oligooclase granite gneisses appear to be the result of the crystallisation of the residuum squeezed off from the earlier formed microcline, thus containing a concentrate of biotite, oligoclase, and apatite.

(e) *Xenoliths in the Lower Granite Gneiss.*

Numerous oval areas of foreign enclosures varying from several yards in diameter, to elongated masses up to 10 chains in length have been noted in the Lower Gneiss. They are most abundant in the eastern part of the area (Plate I). Most are poorly exposed and, with several exceptions, the contacts with the enclosing gneiss are obscured by soil. The mapping, however, indicates that they are lenticular bodies completely surrounded by granite gneiss. The amphibolite enclosures are frequently traversed by quartz-felspar veins coming from the granite gneiss, thus establishing their pre-gneiss age. The longer axes and foliation of the enclosures strike parallel to the banding in the surrounding gneiss. There is considerable variety amongst these xenoliths and the main types will be considered separately as follows:—

(i) *Eulysitic rocks.*—These rocks are scarce in this area, but their occurrence is of interest since they bear similarities to rocks occurring as bands in the Bolgart greenstones to the north of Toodyay, and since they are representatives of the somewhat rare eulysites.

They are found in a small xenolith 10 chains S., 223 chains E. of datum (Plate I), entirely surrounded by gneiss. Nearby xenoliths are greenish "hornblendites."

Two rocks were collected from this locality and in view of their somewhat different character they will be described separately.

Banded quartz-magnetite-hypersthene rock (Spec. No. 15451).

This is a heavy, coarsely-banded type made up of bands (3 mm. wide) of silky lusted lamellar hypersthene, alternating with darker magnetite bands from 1 to 2 mm. wide. The rock is considerably weathered and iron stained, and its feeble magnetic character indicates that the magnetite has gone largely to fine granular martite.

The hypersthene is usually found with its longitudinal cleavage at about 45° to the banding. It has a poikiloblastic structure, enclosing both quartz and magnetite, and the original bedding has been preserved in the wide bands of magnetite and the thin parallel bands of fine granular ore which traverse

the hypersthene (figure 13B). The hypersthene shows a fine lamellar structure. Cleavage is poorly developed, but there is a good parting on 010. Although brownish (due to slight weathering), the weak pleochroism is still visible. Its characters— $X = a$; $Y = b$; $Z = c$; $(-2V) = 83^\circ$; $\gamma = 1.765$; $a = 1.745$ —indicate an iron rich hypersthene with approximately 85 per cent of the orthoferrosilite molecule (Henry, 1935, p. 223). Comparing the above data with those given by Henry (p. 223) for the iron rich hypersthenes, it will be seen that this hypersthene agrees almost exactly with the data given for the hypersthene in the eulysite from Mansjo, Sweden, which has $(-2V) = 83^\circ$; $\gamma = 1.769$; $a = 1.751$. This is the most iron rich type described by Henry (containing 44.93 per cent FeO).

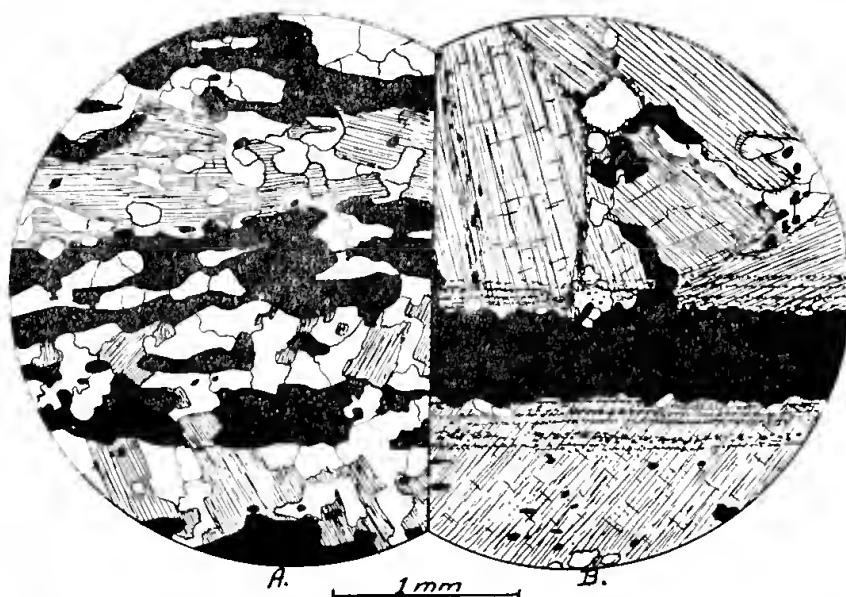


Fig. 13.
Banded eulysitic rocks.

A. Quartz-hematite-grunerite rock (No. 15452).

B. Quartz magnetite-hypersthene rock, showing original bedding preserved in the parallel trains of small magnetite grains included in hypersthene. The hypersthene is altering along its edges and along irregular cracks to a fine fibrous ferro-anthophyllite.

The hypersthene is altering to a more fibrous, highly birefringent amphibole, both around its edges and along irregular cracks. Some of the hypersthenes are completely replaced by this material. The optics of this amphibole are $Z = c$; $(-2V)$ large; $\gamma = 1.687$, and it is therefore a ferro-anthophyllite with approximately 60 per cent FeSiO_3 .

Quartz and magnetite are the only other constituents with the exception of rare apatite. Both are closely associated and there is no sign of reaction between them. The magnetite is in bands up to 2 mm. wide and in trains of small grains (parallel to the bedding) included in hypersthene. In places, tongues of magnetite connect successive bands of iron ore. The almost non-magnetic character of the rock indicates that the magnetite has gone to fine granular martite, and this is confirmed by the cherry red streak of the dark bands. On the outer portion of the rock the reddish hematite can be seen replacing the magnetite, and the change throughout the rock is ascribed to oxidation due to weathering. A very different occurrence of hematite is seen in the other specimen from this xenolith which is described below.

The mineralogical composition (by volume) of the hypersthene rock is approximately—

Hypersthene	....	....	....	60 %
Ferro-anthophyllite	....	....	....	15 %
Martite (after magnetite)	....	....	....	15—20 %
Quartz	....	....	....	5 %
Apatite	....	....	....	Accessory.

Banded quartz-hematite-grunerite rock (15452).

This specimen is from the same locality as (a) above—the field relations between the two types are obscure.

It is a finely banded, even-granular rock, and consists of alternating dark coloured bands of recrystallised hematite and pale greenish quartz-amphibole bands varying in thickness from 0.5 to 1.0 mm. The specimen is non-magnetic—this, together with the deep red streak confirms the determination of the silvery grey, metallic mineral as hematite.

Under the microscope the structure is even-grained granoblastic gneissic, the hematite occurring in recrystallised grains and aggregates showing a marked segregation into bands (figure 13A)—quartz is often included in these aggregates and shows no signs of reaction with the hematite.

The amphibole and quartz form a granoblastic aggregate, the latter often occurring as poikiloblastic inclusions in the former. The amphiboles have a random orientation in the rock, although in particular bands they tend to show the same orientation throughout.

This amphibole is a pale greenish weakly pleochroic variety in irregular shaped prisms with lamellar structure. The prism faces are fairly well developed, but the terminations, whether in contact with quartz or iron ore, are irregular. It has good 110 cleavage and commonly shows multiple twinning on 100. The optics are $\alpha = 1.635$; $\gamma = 1.660$; $\gamma - \alpha = .025$; $Z \wedge c = 15^\circ$; $(-)2V$ near 90. Opt. ax. pl. $\parallel 010$.

The refractive indices indicate a chinningtonite with 42 per cent $FeSiO_3$, but the negative optieal character suggests admixture of the actinolite molecule. Richarz (1927, p. 700) has described a similar amphibole from the Lake Superior District. It has $Z \wedge c = 15^\circ$; $\gamma = 1.680$; $\beta = 1.668$; $\alpha = 1.665$; $\gamma - \alpha = .025$; $(-)2V$ near 90° and composition:—

Al_2O_3	....	....	....	5.3%
Fe_2O_3	....	....	....	11.8%
FeO	....	....	....	22.4%
CaO	....	....	....	2.8%
MgO	....	....	....	5.4%

thus differing from grunerite in its high Fe_2O_3 and Al_2O_3 content. In its optics it closely resembles the Toodyay mineral which is probably an aluminous type of grunerite with admixture of actinolite molecules.

The origin of the banded eulysitic types.

The preservation of well marked banding in these rocks is indicative of their origin from sedimentary, bedded iron ores.

In their appreciable MgO content, and, in the case of type (b), the possible presence of CaO, the original rocks would appear to have been impure banded siliceous ankerite rocks rather than greenalites. In the hypersthene-

quartz-magnetite rocks, the original carbonate must have been largely siderite with but small admixture of magnesite. The metamorphism has been effected under thermal, rather than regional conditions, as evidenced by the complete lack of orientation in the amphiboles and orthopyroxenes formed during this period.

In the case of the quartz-hematite-grunerite rock (*b*), it would appear that limonite was a constituent of the original quartz-carbonate sediment, and has, by re-crystallisation given rise to well crystallised hematite without any reaction with the quartz. SiO_2 has reacted only with the (Fe, Mg) carbonates to give rise to the grunerite. Such a quartz-limonite-iron carbonate rock is known amongst modern bog iron deposits (Van Bemmelen, 1900, p. 319).

The presence of considerable MgO and possibly CaO, and the variable proportions of quartz, iron ore, and amphibole (or hypersthene) throughout the rock seems to indicate that greenalite cherts were not the sediments from which the eulysitic rocks were derived, and while the sedimentary origin is clear, there is some doubt regarding the original character of the sediment, but it appears most probably to have been a banded limonite-iron carbonate rock.

(ii) *Calc-silicate rocks*.—Xenoliths of this type have only been noted in one place (114 chains N., 113 chains E. from datum). The rocks form a well defined band in the coarse porphyritic gneiss, running parallel to the strike of the enclosing rocks. The lime silicate rocks occur in bands and lenses running through a band of white vein-like quartz.

The rock is similar to specimen 1249 (described earlier), differing only in the relative proportions of diopside and grossularite, and in being more siliceous. It has the following approximate mineralogical composition (Vol. %):—

Quartz 50 per cent, diopside 18 per cent, epidote 5 per cent, grossularite 25 per cent, amphibole and sphene 2 per cent.

Isotropic grossularite is the only idioelastic mineral, and it encloses diopside and occasionally quartz.

Diopside, which is not enclosed by grossularite, is altering to a fine fibrous colourless amphibole.

These rocks undoubtedly have the same origin as the lenses of lime silicate rocks in the lower quartzites. They represent xenoliths of the Jimperding metasediments which have been caught up in the intrusive porphyritic microcline granite.

(iii) *Cordierite-anthophyllite rocks and related types*.—These rocks are found in a large xenolith in the granite gneiss at a position 236 chains E., 177 chains S. from datum. The occurrence is more or less circular in shape and about 5 chains in diameter. It consists largely of anthophyllite-hypersthene-pleonaste rocks, but several other types, viz., cordierite-anthophyllite and biotite-clinochlore-anthophyllite rocks are found here.

These rocks have been fully described elsewhere (Prider, 1940), but the chemical analyses are repeated here in Table 3. The conclusion regarding the origin of these anthophyllite-hypersthene-spinel rocks is that they were derived from a hypersthene magma contaminated by aluminous material. The cordierite-anthophyllite assemblages were developed from the spinel hyperstheneites during the period of intrusion of the granite gneiss, by the addition of silica from the granite magma.

TABLE 3.

Analyses of cordierite-anthophyllite rocks and related types from Toodyay, W.A. (quoted from Prider, 1940, p. 377).

		1.	2.	3.	4.
SiO ₂	...	30.91	30.83	33.20	49.73
Al ₂ O ₃	...	21.36	20.47	19.75	12.70
Fe ₂ O ₃	...	19.97	9.23	3.36	4.56
FeO	...	—	11.28	13.23	12.27
MgO	...	23.57	16.10	21.57	16.59
CaO	...	Tr.	Tr.	Nil	Tr.
Na ₂ O	...	Nil	0.36	0.24	0.40
K ₂ O	...	Nil	5.18	0.22	0.54
H ₂ O+	...	2.58	4.87	8.43	2.77
H ₂ O-	...	0.90	0.42	0.10	0.12
TiO ₂	...	1.66	0.70	0.06	0.21
P ₂ O ₅	...	Tr.	nd.	nd.	Tr.
MnO	...	0.16	0.07	0.14	Nil
Cr ₂ O ₃	...	0.17	Nil	Nil	Nil
		101.28	99.51	100.30	99.89

1. Olivine-spinel-anthophyllite-hypersthene rock, Toodyay, W.A.
2. Biotite-clinochlore-magnetite-corundum rock, Toodyay, W.A.
3. Corundum-spinel-anthophyllite-cordierite-clinochlore rock, Toodyay, W.A.
4. Biotite-cordierite-anthophyllite rock, Toodyay, W.A.

(iv) *The Amphibolite Xenoliths.*—Amphibolites, varying from almost pure hornblende rocks to quartz-plagioclase amphibolites in which the felsic minerals are in excess of hornblende, are the most abundant xenolithic types in the lower gneisses. They are found in lenticular masses, measuring up to 10 chains long x 3 chains wide, and in thinner bands which may be traced for greater distances. The elongation and lamination in the amphibolites are parallel to the strike of the enclosing gneiss. The occasional presence of narrow sill-like veinlets from the granite gneiss at the edges of the amphibolite masses indicates the intrusive character of the gneiss. There has, in some instances, been a considerable hybridisation of the granite gneiss, which has been changed from its normal character into a more basic hornblende granite gneiss.

These amphibolites comprise a number of types which are illustrated by the following description of typical members:—

Quartz-plagioclase amphibolites.

These vary from medium-grained dark coloured rocks with a visible lamination (15438) to types with a more granular structure in which no lamination is visible (e.g., 15444).

The former are darker and more granular than the hornblende schists described earlier in this paper. The non-foliated granular type of amphibolite is the most common, and No. 15444 will be described as typical of this group. In hand-specimen it is a dark coloured granular rock with only a slight trace of parallelism of the hornblende which is the dominant constituent. It is a dark green variety in well shaped prisms 1 mm. in length, the interspaces between these prisms being occupied by light coloured fine granular felsic material.

Under the microscope the structure is granoblastic, and the rock is made up of brown-green hornblende (65 per cent), saussuritised plagioclase (15 per cent), clear oligoclase-andesine (10 per cent), quartz (10 per cent), with

accessory epidote, magnetite, and sphene. The amphibole is idioblastic (figure 14A), in prismatic forms up to 2 mm. in length, usually clustered together, these groups being separated by finer granoblastic quartz-plagioclase aggregates.

Some of the hornblende has a poikiloblastic structure carrying rounded inclusions of quartz, magnetite, and, more rarely, plagioclase. It is a much deeper coloured variety than that developed in the hornblende schists interbedded with the quartzites, and has pleochroism:—X yellow-green; Y dark olive green; Z deep bluish green; and absorption $X < Y \geq Z$, $\beta = 1.675$. Both quartz and plagioclase are xenoblastic. Two varieties of the latter are present in approximately equal amount (1) a completely saussuritised variety, and (2) a clear rarely twinned variety often showing slight zoning. It is an oligoclase-andesine near Ab_7An_3 .

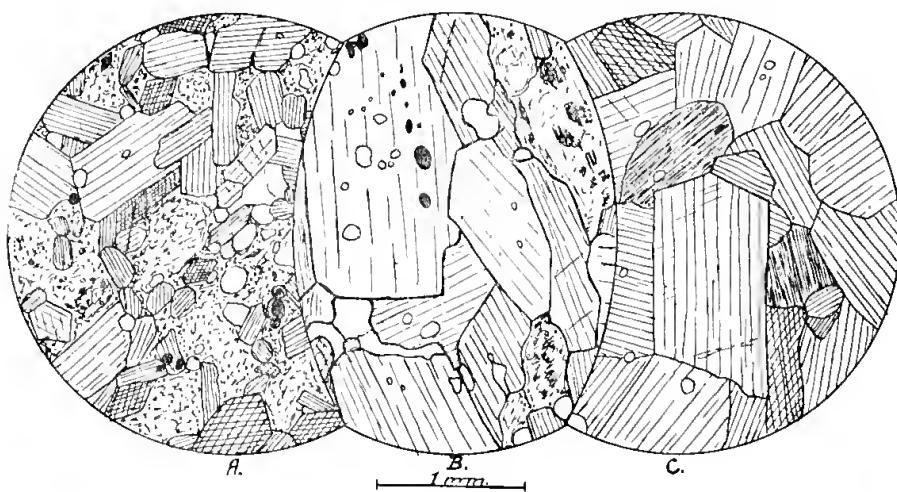


Fig. 14.

Amphibolite xenoliths in the Lower Granite Gneiss.

A. Medium grained plagioclase amphibolite (15444). Constituents are: hornblende, turbid plagioclase, quartz, magnetite with rims of sphene.

B. Coarser amphibolite (15441), showing poikiloblastic inclusions of quartz and magnetite in hornblende.

C. "Hornblendite"—Rare poikiloblastic inclusions of quartz in the hornblende.

Magnetite is the most abundant accessory and is invariably rimmed with sphene indicating its origin from ilmenite. Epidote and apatite are rarer accessories.

In coarser grained varieties (e.g., 15441), the felspar is completely replaced by a fine granular sericite-epidote aggregate, and the larger, more abundant hornblende plates show a well developed poikiloblastic structure (figure 14B) with inclusions of quartz and magnetite, the latter often with a narrow rim of yellow highly birefringent epidote.

"Hornblendites."

With a decrease of the quartz-felspar content the quartz-plagioclase amphibolites pass into almost pure hornblende rocks in which the only other constituent is an occasional small grain of quartz. 15436 is an example—in hand specimen it is made up of a granular aggregate of hornblende (figure 14C), noticeably lighter in colour than in the above types. Under the

microscope many of the hornblende prisms carry small rounded poikiloblastic inclusions of clear quartz. Rare felspar is evidenced by the occurrence of small patches of fine granular epidote.

Pyroxene-plagioclase amphibolites.

These rocks are similar to the quartz-plagioclase amphibolites with the addition of a pale greenish diopside. They are like many of the hornblendic rocks of the Lewisian of Scotland.

No. 15445 is typical (figure 10A). It is coarse, even-grained, granoblastic, with no tendency to gneissic structure. The constituents are hornblende (60 per cent), diopside (25 per cent) and oligoclase (15 per cent), with accessory quartz and apatite.

The hornblende, in plates to 3 mm. diameter, sometimes moulded around diopside, is a brownish-green variety similar to that in the quartz-plagioclase amphibolite. It is noticeably paler in colour at its junction with the diopside. Poikiloblastic quartz inclusions are common.

The pyroxene is a pale greenish diopside with $Z \wedge c = 38^\circ$. It has a curious mottled appearance due to small platy inclusions of pale green hornblende, which appear to be developing at the expense of the diopside.

The felspar is an oligoclase (Ab_4An_1) with fine albite twinning, occurring in subhedral to anhedral grains which are, in places, associated with hornblende in a sub-ophitic fashion.

Apatite, in euhedra averaging 0.2 mm, is the most abundant accessory. Quartz is very rare.

Chemical Composition of the Amphibolites.

Specimen 15441 (described above) was analysed as representative of the most widespread type. The analysis appears in Table 1, column 3. The similarity to the schistose plagioclase amphibolites 1 and 2 is at once evident. The igneous character of these rocks has been noted on an earlier page and need not be considered further here. Except for its slightly higher alumina and low lime and magnesia, this amphibolite analysis agrees very closely with that of the later dolerites (Table 1, col. 4) from this area.

The amphibolites, then, appear to be derived from basic igneous rocks approximating to dolerites or quartz dolerites in composition. Tilley (1921, pp. 98-116), who has described a number of amphibolite enclosures in the granite gneisses of the Southern Eyre Peninsula, South Australia, which are, in many ways, similar to those found at Toodyay, has outlined (pp. 108-109) the chemistry of the conversion of pyroxene to amphibole and little would be gained by repeating this here.

Where the hornblende becomes more abundant in these xenoliths its crystals become larger and apparently more aluminous at the expense of the plagioclase. Quartz persists, as a by-product of the amphibolitisation, even in the almost pure hornblendic types.

The pyroxene-plagioclase amphibolite xenoliths appear to represent completely recrystallised older basic rocks, such as occur in sill-like bodies of pre-tectonic age, interbedded with the Jimperding metasediments. The grain of these rocks has become coarser as a result of the recrystallisation of the amphibole. Basic xenoliths are often of fine grain (Joplin, 1935, p. 233) ascribed in part to the disruption of highly poikilitic crystals of hornblende. In the Toodyay gneisses the amphibolites have not suffered any such breaking up of the hornblende.

(f) *Hybridisation of the granite gneiss.*

There is a considerable development of quartz-oligoclase-hornblende gneisses in the Lower Gneiss as a result of hybridisation of the granite by basic inclusions. These types are well developed 80 chains N., 300 chains W. of datum, where the lower gneiss is seen to transgress the bedding of the hornblende schists and metasediments. The gneisses are of variable composition averaging :—

Hornblende	....	....	30 to 35 per cent (by volume).
Oligoclase	....	....	45 to 50 per cent.
Quartz	....	....	15 per cent.
Chloritised biotite	....	....	5 to 10 per cent.

Microcline is rare and the accessories are : magnetite, sphene, epidote, and apatite. The plagioclase is usually much saussuritised but when determinable is an oligoclase (Ab_4An_1). The hornblende is a slightly deeper coloured variety than in the associated schists, and the biotite is the characteristic greenish

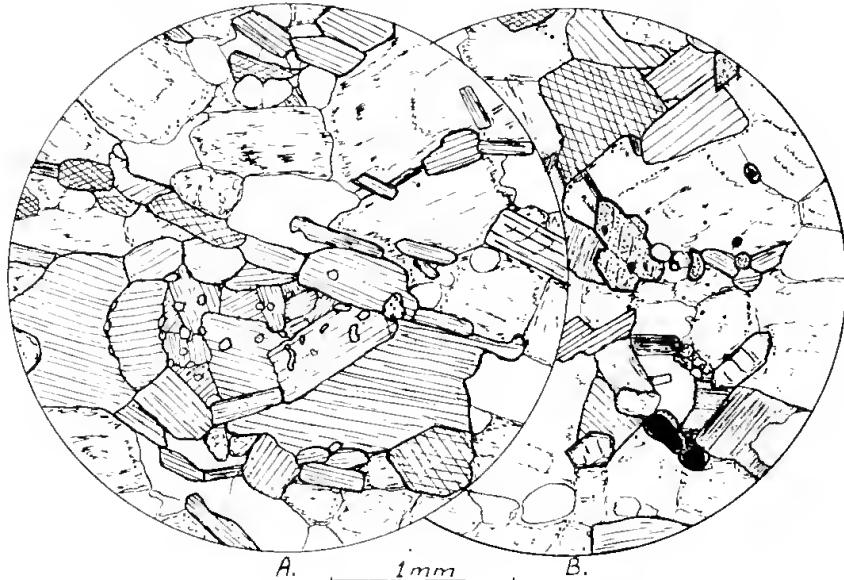


Fig. 15.
Granite gneiss—amphibolite hybrids.

A. 15640. Showing clotted aggregates of hornblende (often with poikiloblastic structure). The other constituents are turbid plagioclase and clear quartz.

B. 15397. Hornblende granite gneiss. Constituents are deeply coloured hornblende, somewhat fibrous pale greenish amphibole, oligoclase, quartz, idioblastic sphene (with central ore inclusions) and apatite.

chloritised variety, with sagenitic rutile inclusions. The hornblendes are often clustered together (fig. 15A) and may have a poikiloblastic structure. In specimen 10420, lenticular remnants of schistose plagioclase amphibolite are present in a hornblende-granite gneiss.

A hornblende-granite gneiss (15397) from the vicinity of a coarse amphibolite enclosure has been analysed (Table 4, No. 2) and will be described in some detail. It is an even granular rock with a gneissic structure and it contains several sill-like quartz-felspar layers.

Under the microscope the constituents observed were: blue-green hornblende (20 per cent), oligoclase (55 per cent), quartz (20 per cent) with diopside, sphene, magnetite, apatite, and microcline as accessories. The structure is granoblastic with no tendency to parallel alignment of the constituents.

Hornblende, usually idioblastic, occurring in small lenticular clots is, in places, altered to a paler greenish fibrous amphibole. Xenoblastic oligoclase ($Ab_{87}An_{13}$), in slightly turbid grains averaging 1 mm. diameter, is the only felspar—it occurs in granoblastic aggregates with quartz and is frequently elongated slightly, parallel to the banding. The absence of microcline is unusual, but is explained by the fact that the microcline in the granite gneiss has crystallised early, forming large phenocrysts, and that specimen 15397 is the result of the reaction between the residuum and the basic xenoliths. Apatite, magnetite, and sphene are all abundant accessories; the sphene is usually idioblastic and carries central inclusions of magnetite (fig. 15B).

The analysis of this rock, together with that of the microcline granite gneiss and coarse plagioclase amphibolite appears in Table 4. It is clearly intermediate between the other two types. The main discrepancy is in the alkalis, but this, as noted above, is due to the removal of the microcline phenocrysts from the magma prior to its reaction with the amphibolite.

TABLE 4.

Analysis of Hornblende Granite Gneiss (Col. 2) compared with Coarse Plagioclase Amphibolite (1) and Microcline Granite Gneiss (2).

		1.	2.	3.
SiO_2	...	49.05	64.16	71.85
TiO_2	...	1.07	0.74	0.25
Al_2O_3	...	15.03	15.12	15.00
Fe_2O_3	...	3.16	1.95	0.55
FeO	...	9.08	2.90	1.20
MgO	...	6.96	2.13	0.42
CaO	...	10.47	6.63	1.52
Na_2O	...	1.70	4.48	3.67
K_2O	...	0.95	0.20	4.45
H_2O+	...	1.43	0.67	0.54
H_2O^-	...	0.25	0.04	0.02
MnO	...	0.09	0.18	trace
P_2O_5	...	0.08	0.32	0.11
FeS_2	...	0.13	0.15	nd.
Total	...	99.45	99.67	99.58

1. Coarse amphibolite xenolith (refer Table 1, No. 3), Toodyay.
2. Hornblende granite gneiss (No. 15397), Toodyay. Analyst, R. T. Prider.
3. Biotite-microcline granite gneiss (Table 2, No. 1).

Much more work, both field and laboratory, is required before any definite statement can be made regarding the origin of these acid hornblende bearing gneisses. So far as examined, however, they appear to represent a hybridisation of the intrusive granite gneiss.

(g) *Summary of the conclusions regarding the origin of the Lower Granite Gneiss and the associated xenoliths.*

The gneiss is essentially the same as the upper band but has not suffered such granulation—it is essentially a porphyritic granite, with flow orientation of the microcline phenocrysts. A less abundant biotite-oligooclase gneiss is considered to represent a more sodic phase of the main mass, which crystallised from residuum squeezed out from the earlier phenocrystal microcline. Late stage veins of garnet-aplite and pegmatite are developed from this magma.

Xenoliths of various types are described :—

- (1) Eulysitic types developed from banded iron ores, probably sideritic and other carbonate types.
- (2) Grossularite-diopside-quartz rocks derived from impure argillaceous limestones.
- (3) Cordierite-anthophyllite rocks and related types derived from ultrabasic igneous rocks.
- (4) Amphibolites, resulting from the reconstitution of basic igneous rocks.

B.—*The Younger Igneous Intrusives.*

(1) *The Granites.*

The later non-foliated granites are confined to the south-west part of the area where they are intrusive into the series described above. The granites are cut by later pegmatites, aplites, and quartz veins, which often penetrate the nearby metasediments and which are considered to be the source of the auriferous deposits found in the mica schists close to the granite.

The granites are always medium to coarse even-grained, remaining coarse-grained right to their contact with the metamorphic rocks, indicating that intrusion took place at some depth into already heated sediments. There is no sign of the porphyritic and foliated structures seen in the older granites occurring as bands in the Jimperding Series.

The later granitic intrusions are represented by three phases, which may be described briefly as follows :—

- (a) *The normal granites* are coarse textured rocks consisting of quartz, slightly perthitic microcline, sericitised oligoclase (Ab_4An_1 , often with zonal alteration), abundant myrmekite, irregular chloritised biotite flakes with intergrowths of epidote, and accessory apatite and sphene. In their mineralogical composition these rocks are very similar to the older granite gneisses described above.
- (b) *Garnet-muscovite granites* are even, fine to medium grained, allotriomorphic granular structured rocks made up of quartz, slightly perthitic microcline, oligoclase and muscovite, with accessory pink garnet (altered along irregular cracks to greenish biotite) and a little brownish biotite. These represent a hypabyssal phase of the granite and occur as dykes in the metamorphics close to the main granite mass.
- (c) *Pegmatites, garnet aplites, and later quartz veins* represent the final phase of the granite intrusion. They are found in dykes and veins in both the granite and adjacent metamorphics. The pegmatites are coarse grained microcline and muscovite bearing types, in which the presence of molybdenite, columbite, and beryl have been noted—the two latter by Simpson (personal communication).

The garnet aplites are the fine grained equivalent of the garnet-muscovite granites. The prevailing texture is fine equigranular granitic, and the constituents are quartz, microcline, and oligoclase with accessory biotite (rare) and small pink garnets. The aplites often form a part of the pegmatite veins.

White quartz veins, representing the final ultra-acid phase of the granite, are fairly numerous in the metamorphics close to the granite. A flat dipping quartz vein in a roof pendant of mica schist in the granite has been proved to be auriferous, a test parcel (50 tons) of this ore mined several years ago yielding 15 dwt. gold per ton.

(2) *The Greenstones.*

(a) *Quartz dolerites.*—These are the latest intrusives into the Jimperding Series. They occur as dykes up to five chains wide, most of which trend a little W. of N., although there are several large dykes with an E.-W. trend. The geological map (Plate I.) shows the distribution of these dykes. They all belong to the same period of intrusion and no examples of one dyke being cut by another were found. This period of intrusion was much later than the last orogenic movements in this region and the doleritic rocks show no alteration other than those of deuteritic character.

They are variable in grain from fine basaltic to coarse gabbroidal, and ophitic texture is characteristic except where obscured by extensive uralitisation of the pyroxene in the more acidic types.

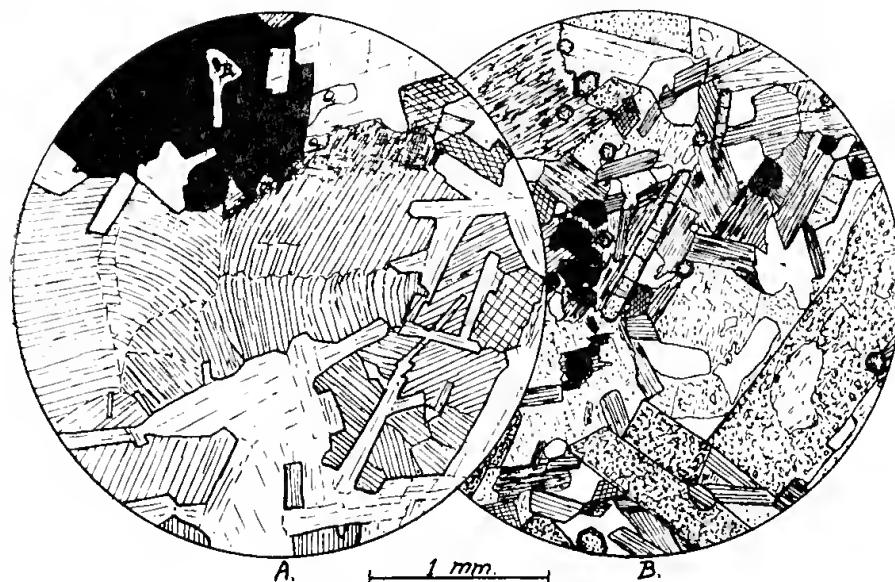


Fig. 16.
Quartz dolerites

A. Quartz rare. Both pyroxene and plagioclase are unaltered. The ophitic texture is well marked. The pyroxene cleavages are slightly curved and incipient fracturing is noticeable. A little primary brown green hornblende is seen in upper right in the vicinity of the end phase quartz. The iron ore is ilmenite.

B. End phase of the quartz dolerite magma showing a concentration of quartz and apatite. Fibrous uralite replaces pyroxene (upper left) and the idiomorphic plagioclase is highly saussuritised. The ferromagnesian is mainly a brownish "primary" hornblende.

The rocks vary from quartz-free dolerites made up of slightly brownish pyroxene and plagioclase (Ab_1An_1) with apatite and ilmenite as accessories, through quartz dolerites which usually show considerable uralitisation of the pyroxene, to more acidic types made up largely of plagioclase, uralitised pyroxene, primary brown-green hornblende, and quartz, with leucoxenised ilmenite and apatite as abundant accessories. The uralitisation of the pyroxene is definitely a deuteritic process in these rocks because there are no later intrusives or earth movements which could have effected these changes, because it is developed much more extensively in types in which the end stage quartz has been concentrated, and also because both unaltered and highly uralitised rocks occur in the same dyke.

The microscopic characters of quartz dolerites have been so frequently and fully described that little space will be devoted to the description of the Toodyay quartz dolerites which do not differ in any way from the normal type of this rock. The only variations are in the proportion of micropegmatite and the degree of deuteritic alteration.

The minerals developed in these rocks are:—

Pyroxene, which is always a pale brownish, non-pleochroic, monoclinic variety, of subhedral to euhedral development, usually penetrated ophitically by plagioclase. There is no zoning and only one type is present. Twinning on 100 is common. The extinction $Z \wedge c$ is $38-41^\circ$ and $2V$ is somewhat variable in different grains from 42° to 48° (measured on the universal stage) and $\gamma = 1.720$. The data indicate a pyroxene intermediate in character between pigeonite and the diopside-hedenbergite series. In some instances, the cleavages of the pyroxenes are bent and the crystals show incipient fracturing (fig. 16A). Alteration to a fibrous greenish uralite is common, proceeding from the periphery to the centre and often completely replacing the pyroxene.

Plagioclase is the most abundant constituent. It is in long columnar and lath-like crystals with well-defined edges in the prism zone and poorer terminal faces. Fine lamellar twinning, both albite and pericline, together with simple Carlsbad twinning are commonly developed. The main felspar is a labradorite about $Ab_{50}An_{50}$, but it almost invariably exhibits a gradational normal zoning, which in some instances has been to a periphery as sodic as $Ab_{80}An_{20}$, although the general range is from $Ab_{50}An_{50}$ to $Ab_{70}An_{30}$. In many instances the plagioclase is completely replaced by a fine granular saussurite and in such instances there may be a thin outer rim of sodic plagioclase. The sassuritisation, although generally irregularly distributed throughout the grains, seems to commence at the centre. Arborescent growths of a pale greenish weakly birefringent chlorite along cleavages and fractures of the plagioclase are very common. The chlorite appears to come from the fibrous uralitic coating of the pyroxene and its distribution points to the migration of the end stage vapours and liquids along the cleavages of the earlier crystallised felspar.

Iron ores, mainly ilmenite, may occur in skeletal crystals as large as the largest pyroxenes. In some highly uralitised types it is altered to leucoxene (pale greyish in reflected light). Magnetite is present in one dyke to such an extent as to influence compass readings taken in its immediate vicinity. This magnetic feature of the dyke rocks was only noted in this one instance. It is probable, however, that much of the more common ilmenite has magnetite associated with it. The iron ore when in contact with felspar is usually rimmed with greenish fibrous chlorite. The only other ore mineral is pyrite, which is of rare occurrence, occurring in small cubic crystals.

Quartz varies from 0 per cent to 10 per cent. It is in angular grains filling the interstices between plagioclase prisms. In the more acid types it commonly occurs in micropegmatite (along with a dusty acid plagioclase). Angular grains of micropegmatite up to 2 or 3 mm. diameter have been observed. It usually carries needle-like inclusions of apatite.

Amphibole is represented by two varieties:—

- (1) A pale greenish, fibrous uralite with patchy coloration developing around the edges of pyroxene plates and frequently completely replacing that mineral. Although the edges become frayed, the ophitic intergrowth of plagioclase (usually saussuritised in the uralitic rocks) with these uralite pseudomorphs still remains visible.

(2) A brownish well-crystallised hornblende, only found in those dolerites which have abundant end stage micropegmatite. Although at times it appears to be of primary crystallisation, it often develops from the outer edge of the fibrous uralite, where this is in contact with the micropegmatitic mesostasis. It has pleochroism—X yellowish-brown; Y brownish-green; and Z bluish-green.

Biotite is a rare constituent only found in the most acid types, closely associated with the acid mesostasis.

Olivine is extremely rare, having been recognised in one rock only, where it is completely replaced by a dark greenish serpentine.

Apatite is the only accessory generally developed. It is in needles except in the most acid type, in which it builds stout euhedral prisms (fig. 16B).

Epidote, in addition to its occurrence in saussuritised plagioclase, often occurs in narrow veinlets cutting directly across all the above-named minerals.

Chemical composition of the quartz dolerites.

A typical example (No. 15424) showing only a very small amount of quartz and slight uralitisation was analysed and the result appears in Table 5, where it is compared with the average analysis of the Whin Sill rocks. The analysis of the Toodyay rock closely approaches the Whin Sill type, differing only in the somewhat higher lime and magnesia in the former.

TABLE 5.

Analysis of quartz dolerite from Toodyay compared with the average composition of the Whin Sill.

			1.	2.
SiO ₂	...	...	49.13	50.52
TiO ₂	...	...	1.27	2.39
Al ₂ O ₃	...	...	13.13	13.76
Fe ₂ O ₃	...	...	3.65	3.87
FeO	...	...	8.95	8.50
MnO	...	...	0.15	0.16
MgO	...	...	7.64	5.42
CaO	...	...	11.84	9.09
Na ₂ O	...	...	1.72	2.42
K ₂ O	...	...	0.16	0.96
H ₂ O+	...	...	1.72	1.51
H ₂ O-	...	...	0.04	0.76
P ₂ O ₅	...	...	0.14	0.26
FeS ₂	...	...	0.45	...
Others	...	...	...	0.69
			99.99	100.31
Norm.:				
Q	...	...	3.48	
Or	...	...	1.11	
Ab	...	...	14.15	
An	...	...	27.52	
di	...	...	24.88	
hy	...	...	18.33	
mg	...	...	5.34	
il	...	...	2.43	
ap	...	...	0.34	
py	...	...	0.45	

1. Quartz dolerite (spec. 15424), Toodyay, W.A. Analyst, R. T. Prider.
2. Average Whin Sill Type (Holmes and Harwood, 1929, p. 539).

The resemblance of the Toodyay quartz dolerite to other doleritic rocks of the Darling Range near Perth which are considered to be comagmatic, has been noted in a previous paper (Prider, 1941, p. 46).

(b) *Ultrabasic intrusives*.—There are two types of ultrabasic intrusives in this area:—

(i) Completely metamorphosed types, now monomineralic tremolite and actinolite schists, occurring as sill-like intrusions into the Jimperding Series. The age of these rocks is unknown, but as will be shown below, they are probably earlier than the later normal granite.

(ii) Serpentine dykes. One only of these serpentine dykes has been noted in the area mapped. It is about $\frac{1}{2}$ -chain wide and has the same trend as the quartz dolerites. Its age relations with the dolerites are not known.

(i) *Metamorphosed ultrabasic sills*.—Several narrow sill-like intrusions in the quartzite were noted in the vicinity of the R. W. Trig station. They are pale greenish, soft, schistose rocks composed almost entirely of a pale greenish actinolite with $Z \wedge c = 16^\circ$; $\gamma = 1.650$; $a = 1.630$; $(\cdot) 2V$ large. This actinolite occurs in a felted network of fine prisms with the interstices filled with a pale green optically positive chlorite. Irregular-shaped grains of magnetite are scattered uniformly throughout.

Another rock (15641), also a sill in quartzite, consists largely of a felted mass of tremolite prisms with a ground of flaky antigorite dusted with magnetite inclusions.

A similar type is found just below the andalusite schist in the S.W. part of the area and this may be the intrusive which has led to the formation of andalusite. If so, the retrogressive changes in the andalusite, induced by the intrusion of the normal granite fixes these ultrabasic sills as pre-granite in age.

(ii) *Serpentines*.—These rocks are found in a narrow dyke $\frac{1}{2}$ -chain wide and the only available specimen is from a point 28 chains N., 132 chains E., of datum.

It is a fine, even, dark greenish rock with a conchoidal fracture. Numerous minute silvery chlorite flakes are visible in hand specimen. Under the microscope it is seen to be made up of a very fine-grained aggregate of flaky antigorite ($\beta = 1.57$) with occasional relief prisms of tremolite and a later development of chlorite flakes with magnetite inclusions coating the well-marked, crumpled 001 cleavages.

The chlorite is a very pale greenish variety and has $\gamma = 1.595$; $a = 1.589$; $\gamma - a = .006$; and $Z \perp 001$. This mineral, therefore, is a slightly aluminous iron-bearing antigorite.

The rock is a normal serpentine, as shown by the following analysis of Specimen No. 15425.

SiO_2 ...	...	...	...	...	...	40.33
TiO_2 ...	...	...	...	...	...	0.28
Al_2O_3 ...	...	...	...	...	...	2.75
Fe_2O_3 ...	...	...	...	...	...	5.43
FeO} ...	...	...	...	...	...	5.48
MgO} ...	...	...	...	...	...	33.39
CaO} ...	...	...	...	...	...	1.29
Na_2O} ...	...	...	...	...	...	Nil
K_2O} ...	...	...	...	...	...	Nil
H_2O}^+ ...	...	...	...	...	...	10.16
H_2O}^- ...	...	...	...	...	...	0.10
MnO} ...	...	...	...	...	...	0.14
P_2O_5 ...	...	...	...	...	...	Nil
Cr_2O_3 ...	...	...	...	...	...	0.10
						99.45

Analyst: R. T. Prider.

IV. ECONOMIC GEOLOGY.

Gold and the refractory minerals andalusite and sillimanite are the only minerals of economic importance which have been noted in this area.

(1) The *gold deposits* occur in the vicinity of Yinnidong Creek in the south-western corner of the area mapped and have been described by Blatchford (1932), Forman (1935), and Prider (1934, p. 73), and require no further description here. The auriferous deposits appear to be genetically related to the younger non-foliated granite of the south-west part of the Area.

(2) *Refractories*—(a) *Sillimanite*.—Refractory clays derived from the alteration of sillimanite schists of the Jimperding Series have been worked at Clackline for some years (Simpson, 1936, p. 11; Matheson, 1938, p. 13). The sillimanite content of these clays is estimated to vary from 5 to 10 per cent of the rock.

In the Toodyay area, the metamorphism of the Jimperding Series has been effected under sillimanite zone conditions. Although sillimanite occurs in the micaeous schists throughout the area, the best sillimanite deposits noted during the survey were in the country lying to the north-west of Key Farm homestead, where there has been a thickening of the incompetent mica-sillimanite schists during folding. Although rapid variations in the sillimanite content are noticeable, the average sillimanite content over comparatively wide bands is high and in certain bands up to 10 feet wide, the sillimanite (mainly fibrolite) forms up to 70 per cent of the rock. This material constitutes a valuable ore provided the small muscovite-biotite content can be separated. Experimental work in this connection is at present in progress.

(b) *Andalusite*.—This mineral is developed in the uppermost band of mica schist in the south-western corner of the area. There does not appear, in the area mapped, to be any natural concentration of this mineral, sufficient to constitute an economic proposition. However, in the westerly extension of the andalusite mica schists, a mile or so west of the edge of the mapped area, in the headwaters of Mortigup Brook, considerable deposits of white weathered andalusite schist with abundant andalusite are exposed. These deposits are being exploited at the present time by a local company.

V. SUMMARY AND CONCLUSIONS.

A conformable series of metamorphic rocks has been described. It includes both sedimentary and igneous types. The former include interbedded sillimanite- and andalusite-mica schists, extremely pure quartzites, and occasional calcareous sandstones, now represented by eale-silicate rocks. All these rocks lie within the sillimanite zone. Rare biotite-plagioclase schists have been noted, in one instance carrying a considerable amount of gedrite and cummingtonite. This biotite-gedrite-cummingtonite-plagioclase schist is considered to result probably from the regional metamorphism of a somewhat dolomitic clayey sediment.

Interbedded with the sediments there are basic igneous rocks now represented by schistose plagioclase amphibolites, which have been derived by regional metamorphism, under sillimanite zone conditions, from tholeiitic rocks which may have been originally sills or flows. They are older than the first granite intrusion and have been folded along with the associated sediments.

Wider bands of granite gneiss have resulted from the intrusion of granitic magma into the above rocks. The period of intrusion coincided with the orogenic period, when the pre-existing rocks were altered to their present state. The granite, a porphyritic microcline type, was intruded under stress and presents a fluxional structure, which in the upper, more narrow band is

emphasised by the slight shearing out of the microcline phenoerysts into mieroeline augen. Earth movements had praetically ceased by the time that the granite had finally eonsolidated. Late stage aplites and pegmatites were associated with this period of intrusion. This intrusive granite has pieked up fragments of the older rocks, comprising :—

- (1) Plagioelase amphibolites and related types, derived from basie igneous roeks of doleritie eomposition.
- (2) Altered ultrabasic igneous roeks, now represented by anthophyllite-hypersthene and anthophyllite-cordierite roeks.
- (3) Metasediments in the form of banded eulysites (derived from banded iron ores) and biotite granulites (derived from psammitic sediments).

There is no evidence of any teetonic movements of later age than the granite gneiss intrusion.

Later these roeks were intruded by a granitie magma of similar eomposition to the earlier orthogneisses, together with its end stage produets (aplates, pegmatites, and quartz veins). This granite has not effected any metamorphism of the older rocks other than the retrogressive alteration of pre-existing andalusite, by vapours advancing ahead of the intrusive mass. The intrusion of this later granite is considered to have taken place at considerable depth.

A later period of igneous activity is represented by dyke intrusions of quartz dolerite, which in their constaney of trend appear to have come up along joints or other lines of weakness, approximately parallel to the tectonic strike. Certain ultrabasic dykes are believed to be also post-granite.

The structure of the area, which is one of abnormal strike in the Western Australian shield, is interpreted as a major antieline, with its axis striking a little W. of N. and pitching to the south. This structure has a reeumbent syncline on its eastern limb and is cross-folded on axes trending N.N.E.

The geological history of this region may be summarised thus :—

Early Pre-Cambrian (Kalgoorlie-Yilgarn Period)

1. Deposition of argillaceous and arenaceous sediments with a minor caleareous facies and with intercalated lava flows (or sills).

2. Diastrophic period accompanied by intrusion under orogenic stress, of a porphyritic mieroeline granite. Main period of regional metamorphism. No orogeny after this period.

3. Intrusion of end stage produets of the microcline granite magma.

4. Intrusion of the later granite. No further metamorphism.

5. Intrusion of end stage produets of the later granite. Period of formation of auriferous deposits.

6. Intrusion of quartz dolerites.

7. Erosion period.

8. Region reduced to a peneplain. Formation of laterite (Woolnough, 1930, p. 125).

9. Erosion period to the present. The region is now a dissected, laterite-capped plateau.

Late Pre-Cambrian (Nullagine Period)

? Miocene

Present

VI. ACKNOWLEDGMENTS.

The mapping of the area described in this paper has been done by parties of senior students in the Dept. of Geology of the University of Western Australia during the past ten years and the contributions made by these various parties are gratefully acknowledged. The greater part of the laboratory work was done in the Dept. of Mineralogy and Petrology at Cambridge, England, during the tenure of a Hackett Research Studentship from the University of Western Australia, and publication of the paper has been made possible by a grant from the Hackett Fund.

I wish to express my thanks to Professor C. E. Tilley for assistance and constructive criticism during the preparation of this paper, and to Dr. F. C. Phillips for advice in connection with the petrofabric analyses of some of the rocks examined. My thanks are also due to Professor E. de C. Clarke, who first suggested that the Toodyay District should be closely studied, and who has been closely associated with all the field work undertaken in this locality. I wish to thank Professor Clarke also for his guidance in my preliminary studies of these rocks, for his interest and encouragement in the work, and finally, for his assistance during the revision of the text.

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Plate II.

Microcline granite gneiss.

A. Crushed microcline mosaic with sill-like quartz of post cataclasis crystallisation. Nicols crossed. X 20.

B. Later quartz veinlet cutting microcline phenoecyst. Nicols crossed. X 25.



A.



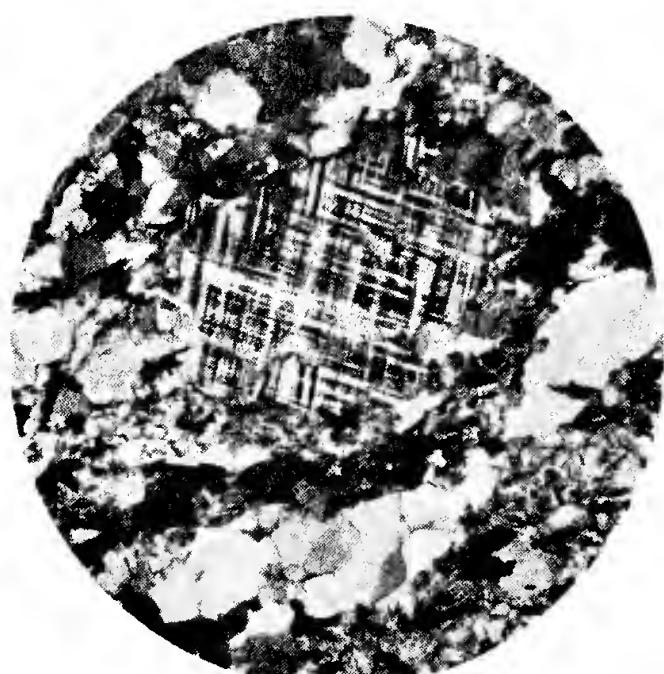
B.

Plate III.

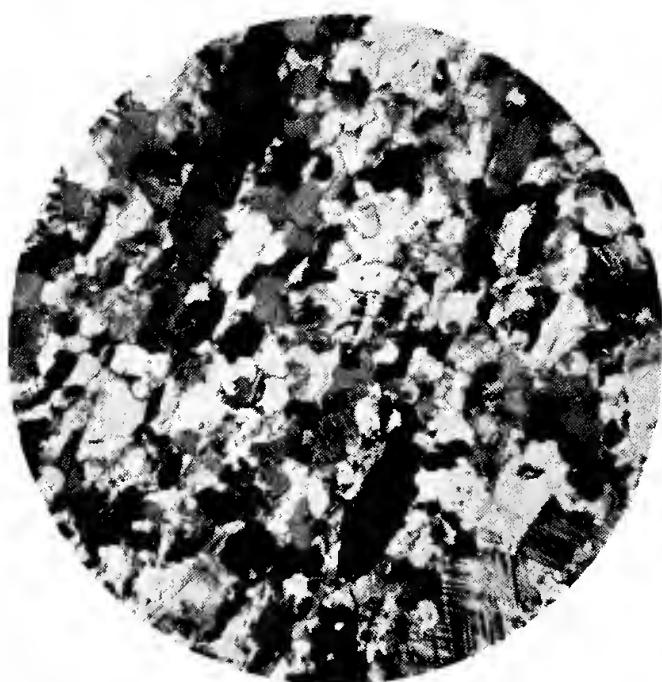
Microcline granite gneiss.

C. Small porphyroblast of microcline, with granulated periphery. Nicols crossed. X 25.

D. Finely granulated microcline granite gneiss. Elongated uncrushed quartz grains abundant. Nicols crossed. X 25.



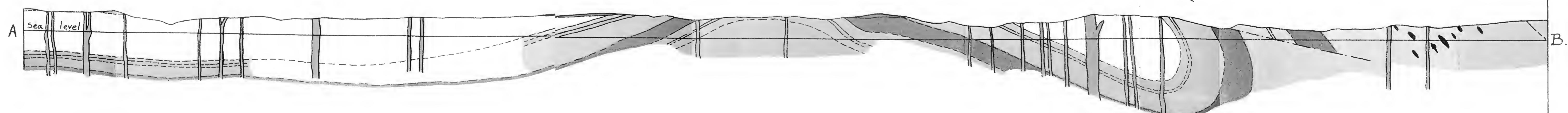
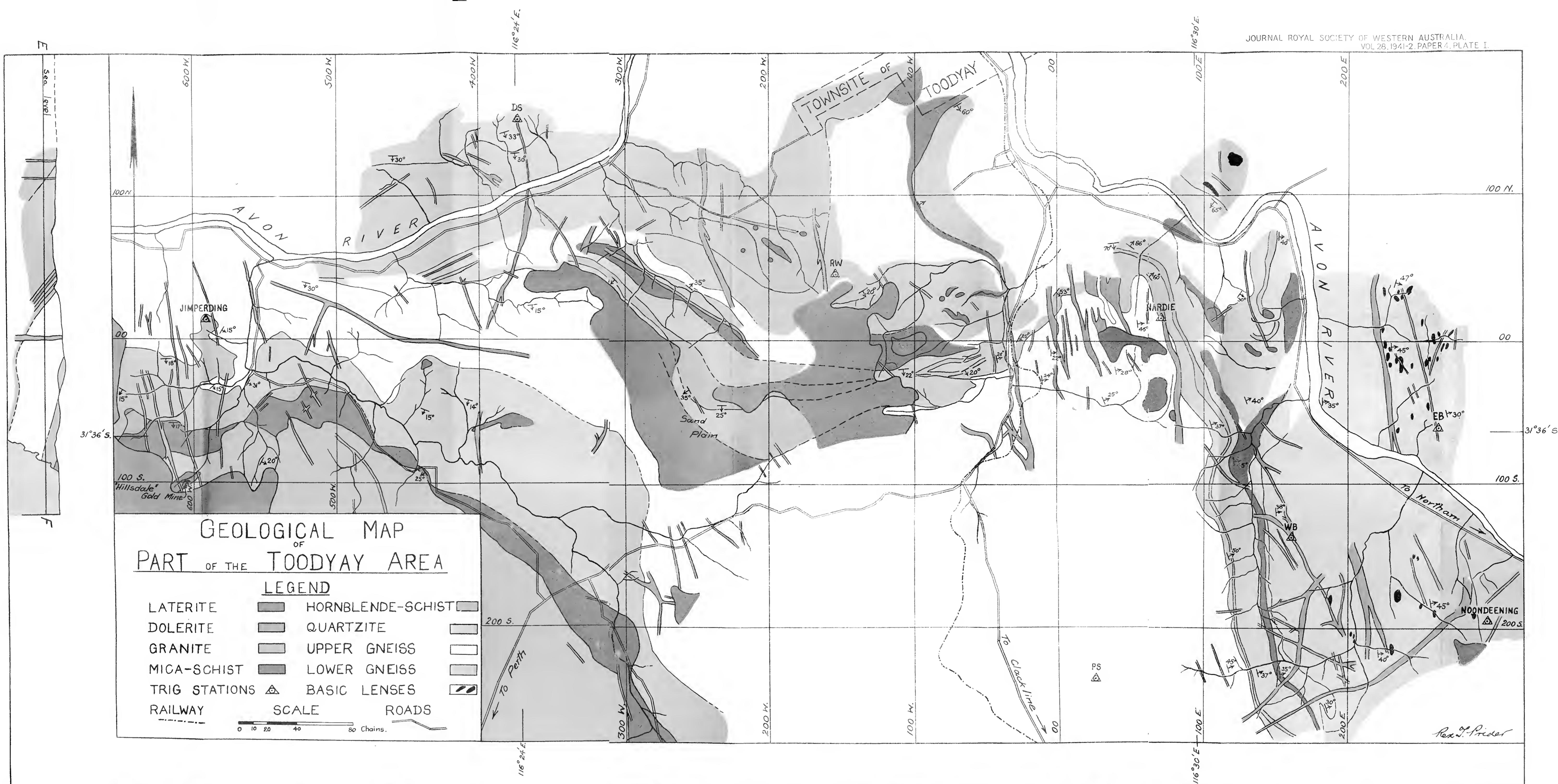
C.



D.

Plate III.







5.—REVISION OF THE EMBIOPTERA OF WESTERN AUSTRALIA.

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Read: 9th December, 1941. Published: 15th March, 1944.

Communicated by L. Glauert.

INTRODUCTION.

The Order Embioptera is well represented in Western Australia, somewhat sporadic collecting having to date revealed five species, of which three are endemic and rather bizarre in structure. Interesting collections have been received from time to time from the Western Australian Museum, by courtesy of the Curator, Mr. L. Glauert, to whom my thanks are due. It is the purpose of this paper to collate the systematic records relating to those species known from Western Australia, and to add certain new locality records. It is hoped that this may lead to further collecting, which would almost certainly result in the discovery of new forms.

GENERAL ORGANISATION.

The Embioptera form a small but distinct Order of Orthopteroid insects, showing some affinity to the Isoptera and to a less extent the Dermaptera and Perlaria, from all of which, however, they are probably separated by a long line of independent ancestry. No distinctly descriptive common name has been applied to these insects; the name "Foot-spinners" is here proposed, referring to the distinctive habit of members of the Order of spinning silken webs from the glands of the fore tarsi.

Apart from the Palaeozoic Sub-Order Protembioptera, with two monotypic genera (*Protembia* Till., *Tillyardembia* Zal.) of ill-defined structure, the Order is represented by about 140 Tertiary and Recent species, distributed through some 36 genera and seven families, of which two are represented in Western Australia, each by a single genus.

The females of Tertiary and Recent genera (Sub-Order Euembioptera) are wingless and larviform, and possess no good taxonomic characters. The males are usually winged, occasionally wingless, while a few species are known within which both forms occur. The two pairs of wings are equal and widely-spaced, and the veins are rather weak. A short subcosta is present; the radius (R_1) is the strongest vein in the wing, its sector arising near the base and forking a little before half the length of the wing to an anterior branch (R_{2+3}), usually fusing with R_1 subterminally, and a posterior branch (R_{4+5}), which may be forked or, as in all Australian species, simple. The media (M) arises separately near the radial sector; it is rarely forked, usually simple, and often only weakly developed. The first cubital (Cu_1) has a strong main axis and an anterior branch (Cu_{1a}), usually weak, but forked once or several times in some exotic genera; there is no second cubital. One small anal vein is present. Cross-veins may be frequent, but their number and position shows individual variation, and they are of no taxonomic significance.

The tarsi of all legs are three-segmented. The first segment of the fore tarsi is greatly inflated, housing the spinning-glands, which discharge by hollow setae on the plantar surface. The second legs are weakly developed. The hind femora are always greatly swollen, housing the enlarged depressor tibiae muscles by whose contraction the insect is able to dart backwards very rapidly. The first two segments of the hind tarsus have their plantar surfaces variously beset with vesicles and stiff setae, these being important systematic characters.

The male terminalia, the most important taxonomic criteria, are best understood by reference to the larval form, with which the adult female agrees essentially except in the presence of a transverse genital aperture on the posterior part of the eighth abdominal sternite. In the larva, the ninth abdominal tergite is transverse, the tenth subtriangular. The ninth abdominal sternite is subquadrate, the tenth divided by a median longitudinal cleft to two triangular hemisternites. Between these and the bases of the cerci are subannular sclerites referred to as cercus-basipodites. These are very probably paraprocts, although American workers (e.g., Snodgrass, 1935, Fig. 140F) refer to the structures here interpreted as hemisternites of the tenth segment as paraprocts. Only a study of the late embryological stages can finally decide this point, which is, however, unimportant in the internal classification of the Order. The cerci are two-segmented, each segment smooth and subcylindrical, the basal one thicker.

In all species except *Clothoda nobilis* (Gerst.) (Amazon region), the tenth abdominal tergite of the male becomes cleft at the last ecdysis, although frequently not to the base, so that two more or less distinct hemitergites are formed; these are furnished with copulatory processes. The right cercus is usually little modified at the last ecdysis, but the first segment of the left cercus is often greatly changed, usually becoming clavate and often developing echinulation on the inner surface. The second segment may remain unchanged or, as in some Australian and North American genera, may be partly or wholly resorbed into the first to form a compound structure.

The ninth abdominal sternite sends out a distal process, which can indeed be detected during the two previous instars in an incipient condition. This process may possibly be equivalent to fused gonocoxites, so that the whole structure may be regarded as a hypandrium. Dorsal to this process is the male genital aperture, usually situated among ill-defined membranous structures. The right hemisternite of the tenth abdominal segment, and the right cercus-basipodite, usually in part degenerate, sometimes remaining as small sclerites unimportant functionally and taxonomically. The left hemisternite and cercus-basipodite may remain distinct in the adult and develop processes, but more frequently they appear to form a composite structure, often with one or more processes, and usually referred to simply as the left cercus-basipodite.

The male terminalia are in some species probably the most complex in the Class Inseeta, the processes of the hemitergites, hypandrium, cerci, and left cercus-basipodite all assisting in holding the unspecialised female terminalia during copulation.

Members of the Order feed predominantly on dead vegetable matter, more particularly bark and fallen leaves. Branching cylindrical tunnels of silk are spun among the food material by means of the tarsal glands, and in these the insects live, being gregarious and subsocial, the female guarding the eggs and young larvae in an enlargement of the gallery. Most of the Western Australian records represent winged males, taken either at light or swarming under weather conditions such as induce this phenomenon in Termites. Search

for the actual colonies may reveal wingless forms of the adult male in species where at present the winged form alone is known, or even new species entirely wingless in all stages, such as in the Eastern Australian genus *Metoligotoma*.

SYSTEMATICS.

Family OLIGOTOMIDAE Enderlein 1909.

Zool. Anz., 35, p. 190. Type genus, *Oligotoma* Westwood, 1837, *Trans. Linn. Soc. London, Zool.*, 17, p. 373.

In addition to the type genus, whose diagnosis is given below, this family includes only the genus *Haploembia* Verhoeff (Shores of Mediterranean and Black Seas), which differs from *Oligotoma* in having the males always, instead of exceptionally, wingless, and in the presence in both sexes of a medial bladder or vesicle on the plantar surface of the first segment of the hind tarsus.

Genus OLIGOTOMA Westwood 1837.

Loc. cit. (as subgenus of *Embia* Latreille, 1829). Raised to generic rank, Burmeister, 1839, *Handbuch der Entomologie*, Bd. 2, p. 770.

Males winged (more rarely, winged and wingless forms occur within the same species), R_{4+5} , M , and Cu_{1a} simple and subobsolescent (each represented by little more than a median row of macrotrichia in a broad band of pigment, Plate I, Fig. 1); tenth abdominal tergite partly divided to hemitergites, the cleft not extending forward to the ninth tergite; right hemitergite with outer margin produced back as a slender sclerotized lobe, basally overlying an inner membranous flap, the latter sclerotized only medially, this sclerotization continuous with that of the outer process. Left hemitergite with a prominent process, sometimes complex. First segment of left cercus subcylindrical to clavate but never echinulate; second segment, and both segments of right cercus, elongate-subcylindrical and distinct. Structures at the base of the left cercus, conventionally referred to as the left cercus-basipodite, often complex, and probably always including elements of the left half of the tenth sternite of the larva.

Both sexes with plantar surface of first segment of hind tarsus carrying only the terminal bladder, remainder of surface carrying many stiff setae (Plate I., fig. 2).

The genus is indigenous in the warmer parts of Asia, throughout Australia, in the islands between Asia and Australia, and islands in the Indian Ocean. It is now tropicopolitan, spread by man.

Oligotoma glauerti Tillyard, 1923 (Plate I., figs. 5-7).

Journ. Proc. Roy. Soc. West Aust., 9, 1, p. 64. Re-described from type series, Davis, 1936, p. 242, Plate I., figs. 6, 13, 20, 27, and 34.

♂ Length 9.5-10.0 mm.; head 1.4-1.5 mm., x 1.1 mm.; forewing 8.2 mm., x 2.2 mm.; hindwing 7.5 mm., x 2.2 mm. Colour mid-brown, eyes black, wings with veins or their traces bordered by pale-brown bands. Head rounded behind; eyes subreniform; antennae with up to 21 segments, maximum total length 7.5 mm.; mandibles (Plate I., fig. 7) slender, left with three thin inwardly-directed teeth terminally and subterminally, right with two; inner margin of left mandible with a median dorsi-ventrally flattened cutting edge. Thorax, including wings and legs, normal for the genus. Terminalia (Plate I., fig 5) with outer process of right hemitergite ending in two closely-approximated subacute teeth; process of left hemitergite (Plate I., fig. 6) ending in an anchor-shaped hooklet. First segment of left cercus irregularly

melanized, distally curved inwards to a tapered obtuse beak. Ninth abdominal sternite tapered, distally smoothly truncale, margin minutely echinulate distally and on the right. Left cercus-basipodite obtuse, curved upwards and inwards and slightly spathulate. Terminalia otherwise as throughout the genus.

♀ unknown.

Locality : Milly Milly Station, Murchison River, 26 v/22, coll. L. Glauert (holotype ♂. W.A. Museum : paratype ♂, Maeleay Museum, Sydney University).

Oligotoma tillyardi Davis, 1936 (Plate I., figs. 8-10).

Proc. Linn. Soc. N.S.W., **61**, 5-6, p. 241, Figs. 5, 12, 19, 26, 33.

♂ *Length* 7.4-9.7 mm. ; head 1.3-1.5 mm., x 1.0-1.2 mm. ; forewing 7.5-8.5 mm., x 1.9-2.0 mm. ; hindwing 6.1-7.2 mm., x 1.9-2.0 mm. *Colour* yellowish-brown, eyes and wings as in *O. glauerti*. *Head* as in *O. glauerti*. antennae with up to 19 segments, maximum total length 4.6 mm. Dentition of mandibles (Plate I., fig. 10) resembling *O. glauerti*. *Thorax* including wings and legs normal for the genus. *Terminalia* (Plate I., fig. 8) with posterior process of right hemitergite as in *O. glauerti* ; process of left hemitergite (Plate I., fig. 9) forcipate, right-hand lobe heavily sclerotized, curved to the left and acute terminally, left-hand lobe more dorsal in position, flat, less heavily sclerotized, obtuse, curved downwards and to the right terminally and excavate on the concave inner side. First segment of left cercus terminally incurved to form a spathulate process. Ninth abdominal sternite tapered, rather sharply truncate, emarginate latero-distally on the left, margin echinulate distally and on right as in preceding species. Left cercus-basipodite slender, tapered, sub-obtuse distally, fixed to left-hand margin of ninth sternite by membrane. Terminalia otherwise as throughout genus.

♀ unknown.

Localities : Morgan's, near Mt. Margaret, x/33 (holotype ♂, Maeleay Museum ; paratype ♂♂, W.A. Museum, etc.) ; Belele Station, Murehison (4 ♂♂) ; Annean Station, near Nannine, Murehison (1 ♂). (Last two, new records.)

Oligotoma approximans Davis, 1938 (Plate I., figs. 1-2, 11-13).

Proc. Linn. Soc. N.S.W., **63**, 3-4, p. 252, Figs. 116-119.

♂ *Length* 6.3-6.9 mm. ; head 1.0-1.1 mm., x 0.9 mm. ; forewing 5.8-7.2 mm., x 1.5-1.7 mm. ; hindwing 4.8-5.9 mm., x 1.4-1.7 mm. *Colour* dark brown, eyes and wings as in *O. glauerti*. *Head* as in *O. glauerti* ; antennae with up to 18 segments, maximum total length 3.5 mm. ; mandibles (Plate I., fig. 13) of same general form as in preceding species, somewhat stouter. *Thorax* including wings (Plate I., fig. 1) and legs (Plate I., fig. 2, hind tarsus) normal for the genus. *Terminalia* (Plate I., fig. 11) with outer process of right hemitergite slender, tapered, obtuse, and slightly outcurved terminally ; process of left hemitergite (Plate I., fig. 12) basally sinuous, distally slenderly tapered, with a flat subtriangular spine arising half-way along the left-hand margin and directed to the left. First segment of left cercus with a small blunt inner lobe about one-third of length from extremity, inner margin basad to lobe concave. Ninth abdominal sternite tapered posteriorly, distally obliquely truncate and slightly emarginate, concavity filled by a projecting membrane. Left cercus-basipodite as in *O. tillyardi*. Terminalia otherwise as throughout the genus.

♀ unknown.

Locality : Fremantle, 20-23/v/35, coll. K. R. Norris (holotype ♂ and paratype ♂, Macleay Museum).

Note.—The three foregoing species are probably the most highly-specialised in the genus, agreeing well with the concept that greater structural change is to be expected in those descendants which have migrated furthest from the ancestral region. They may later be separated as two distinct subgenera, one containing *O. glauerti*, the second the other two species.

***Oligotoma gurneyi spinulosa* Davis, 1936 (Plate I., figs. 14-16).**

Op. cit., p. 239, Fig. 3.

♂ Length 8.7-13.8 mm. ; head 1.7-2.3 mm., x 1.4-2.0 mm. ; forewing 7.0-10.0 mm., x 1.6-2.5 mm. ; hindwing 6.0-9.0 mm., x 1.7-2.5 mm. Colour as in *O. glauerti* or somewhat darker. Head as in preceding species, eyes prominent ; antennae with up to 20 segments, maximum total length 4.2 mm. ; mandibles (Plate I., fig. 16) essentially as in the preceding species except for the presence of a marked excavation in the proximal half of the inner margin. Thorax including wings and legs normal for the genus. Terminalia (Plate I., fig. 14) with outer process of right hemitergite terminating in two approximated subacute teeth, the outer one slightly incurved ; process of left hemitergite (Plate I., fig. 15) slender, sinuous, with a slender acute terminal spine directed forward and to the left. First segment of left cercus with a blunt subterminal inward projection, the inner margin basad to this slightly and smoothly concave. (This structure is distorted in the slide mount of the holotype, Plate I., fig. 14 ; for natural structure see Davis, 1936, Fig. 3, LC₁.) Ninth abdominal sternite tapered posteriorly and terminally smoothly rounded, right-hand margin sinuous. Left cercus-basipodite intimately fused to the left-hand margin of the ninth sternite, subterminally produced to the left as a sharp spine. Terminalia otherwise as throughout the genus.

♀ See below.

Localities : Morgan's, near Mt. Margaret, x/33 (holotype ♂, Macleay Museum ; paratype ♂♂, W.A. Museum, etc.) ; Lake Violet, East Murchison District, x/27 (1 ♂) ; Geraldton (1 ♂) ; and the following new records : Belele Station, Murchison (3 ♂♂) ; Annean Station, near Nannine, Murchison (8 ♂♂, in association with 1 ♂ of *O. tillyardi*, and a female, length 14 mm., colour dark red-brown, and therefore probably referable to *O. gurneyi spinulosa* but larviform and with no apparent specific characters).

***Oligotoma gurneyi* Frogg, 1904, subsp. ?**

A single male from Lalla Rookh Station, North-West Australia (W.A. Museum ; cf. Davis, 1940, p. 159, Figs. 5-6) is intermediate between *O. gurneyi spinulosa* and subspecies occupying a more easterly and northerly range (*O. gurneyi subclavata* Davis 1936, *op. cit.*, p. 240, Fig. 4 : North Australia ; and *O. gurneyi centralis* Davis 1936, *op. cit.*, p. 237, Fig. 2 : Central Australia). A male from Hermannsburg, Central Australia (Davis, 1940a, p. 157, Fig. 7) is barely distinguishable from the Lalla Rookh example, so that this series may have a wide range, and deserve subspecific nomenclature. The first segment of the left cercus is only barely elavate, as in *O. gurneyi subclavata* ; the left cercus-basipodite is blunt and more or less upcurved, suggestive of *O. gurneyi centralis*. The processes of the hemitergites, however, agree most closely with *O. gurneyi spinulosa*.

Further specimens are required, especially (1) from localities between the range of *O. gurneyi spinulosa* (*supra*) and the localities Lalla Rookh and

Hermannsburg ; and (2) from between these latter localities and the type regions of *O. gurneyi subclavata* and *O. gurneyi centralis* respectively. Until some extra records are obtained, it seems premature to name the Lalla Rookh example subspecifically.

Family **NOTOLIGOTOMIDAE** Davis 1940b.

Ann. Ent. Soc. America, 33, 4, p. 681. Type genus, *Notoligotoma* Davis 1936, *op. cit.*, p. 244.

Other genera included in this family are *Metoligotoma* Davis (Eastern Australia), *Ptiloccrembia* Fried. (Java and Sumatra), *Embonycha* Navas (Indo-China), and the fossil *Burmitcembia* Ckll. (Burmese Amber, ? Miocene). The family is thus Indo-Malayan in distribution ; the feature common to all its members is the reduction of the second segment of the left cercus in the adult male, and its fusion, to a greater or a less degree, with the first segment. In all genera where the character has been studied, there is a medial bladder on the plantar surface of the hind tarsus : this is common to both sexes and all stages.

Genus **NOTOLIGOTOMA** Davis 1936.

Loc. cit. Genotype, *Oligotoma hardyi* Friederichs 1914, Ree. W.A. Museum, 1, 3, p. 241.

Australian Notoligotomidae, *males* winged, or with winged and wingless forms in the same species ; R_{4+5} , M, and Cu_{1a} simple, the first two well-developed ; cross-veins relatively frequent ; tenth abdominal tergite completely divided to hemitergites, separated basally by a trapezoidal median sclerite. Right hemitergite with a postero-median process and an inner process, stout and echinulate, curving forward from the anterior end of its inner margin. Inner margin of left hemitergite produced back to a long thin subacute process. First segment of left cercus elavate and echinulate, second less than twice as long as its average thickness, firmly set on the outer and distal part of the first segment and not movably articulated thereto. Left cercus-basipodite fused to left-hand margin of hypandrium, terminally produced to a subobtuse process.

Both sexes with two bladders on plantar surface of first segment of hind tarsus, one medial, the other terminal. (The medial bladder possibly indicates the position of the end of one segment, the basal segment thus being formed of two segments of an ancestral condition closely fused ; this view is supported by the fact that the medial bladder is present in all those genera which on other characters are regarded as primitive.)

Notoligotoma hardyi (Friederichs, 1914) Davis, 1936 (Plate I., figs. 3-4, 17-19).

Op. cit., p. 245. *Oligotoma hardyi* Friederichs, 1914, 1 c.

♂ *Length* 8.8-11.0 mm. ; head 1.5-1.8 mm., x 1.3-1.5 mm. ; forewing 7.9-10.9 mm., x 1.9-2.8 mm. ; hindwing 6.4-9.6 mm., x 1.8-2.7 mm. *Colour* rather pale brown, eyes and wings as in *Oligotoma*. *Head* with eyes prominent, posterior margin slightly incised laterally ; antennae with up to 19 segments, maximum total length 4.3 mm. ; mandibles (Plate I., fig. 19) with dentition as in *Oligotoma*, outer margin sinuous. *Thorax* including wings (Plate I., fig. 3) and legs (Plate I., fig. 4, hind tarsus) normal for the genus. *Terminalia* (Plate I., fig. 17) with right hemitergite produced inwards and backwards to a tapered process, weakly bifid terminally ; inner process hooked, weakly nodulose. Process of left hemitergite (Plate I., fig. 18) narrowest at origin, then slightly expanded, terminally tapered and subacute. Inner margin of

first segment of left cercus irregular and echinulate ; second segment short, subeonical, firmly fused to first segment. Ninth abdominal sternite with a slender heavily-sclerotized finger-like process directed upwards ; left cercus-basipodite with a similar process directed backwards and to the left. Terminalia otherwise as throughout the genus.

♀ See Davis, 1936, p. 246.

Localities : Near Perth, coll. G. H. Hardy (Friederichs' types, no longer extant) ; Caversham, near Perth, vi/15, coll. C. Kerruish (♂♂, W.A. Museum, Macleay Museum, etc. ; *infra*) ; Midland, near Perth, vi/36 and vii/38 (♂♂) ; Cottesloe, 25/v/40 (4 ♂♂ ; new record).

In addition to these localities in Western Australia, the species is known from near Nyngan, N.S.W., and from near Townsville and Rockhampton, Q. (Davis, 1936, p. 246, and 1940a, p. 158).

Note.—It is clear that Friederichs' types have been lost. A male (slide mount ; Macleay Museum) has accordingly been designated neotype. The locality, Caversham, is as close to the original type locality as can be determined ; the specimen agrees with Friederichs' description in all respects.

KEY TO THE SPECIES OF WESTERN AUSTRALIAN EMBIOPTERA.

(Characters are for the adult male ; the tarsal features apply to both sexes and all stages.)

1. R_{4+5} and M well-defined ; first segment of hind tarsus with a medial bladder on the plantar surface ; first segment of left cercus echinulate, second segment of length less than twice average breadth, not distinctly articulated with first *Notoligotoma hardyi* (Fried.). R_{4+5} and M subobsolescent ; medial bladder of first segment of hind tarsus absent ; first segment of left cercus not echinulate ; second segment with length at least three times maximum breadth, and clearly and movably articulated with first segment 2
2. Process of left hemitergite with a terminal hook 3
3. Process of left hemitergite with a lateral process 5
3. Terminal hook of process of left hemitergite projecting to both sides from point of attachment ; margin of ninth abdominal sternite minutely echinulate near right-hand distal angle *Oligotoma glauerti* Tillyard. Terminal hook of process of left hemitergite projecting only to the left from its point of attachment ; ninth abdominal sternite smooth 4
4. First segment of left cercus elavate ; left cercus-basipodite spinescent *Oligotoma gurneyi spinulosa* Davis. First segment of left cercus subcylindrical ; left cercus-basipodite blunt *Oligotoma gurneyi* Frogg., subsp. ?
5. Lateral lobe of process of left hemitergite blunt, spathulate ; outer process of right hemitergite terminally bidentate ; first segment of left cercus very markedly incurved terminally *Oligotoma tillyardi* Davis. Lateral lobe of process of left hemitergite a sharp, flat spine ; outer process of right hemitergite terminally tapered, obtuse ; first segment of left cercus only slightly incurved *Oligotoma approximans* Davis.

Note.—The exotic species *Oligotoma saundersii* Westwood (native of the Indian Region) and *O. humbertiana* (Sauss.) Davis (native of Ceylon) may later be found to occur in North-West Australia. The terminalia of each (cf. e.g., Davis, 1939, Figs. 3, 5) are very distinctive ; the former has a curved spine arising subterminally from the left-hand margin of the ninth abdominal sternite, and curving under this and upwards on the right ; the latter has a prominent tooth on the outer margin of the outer process of the right hemitergite, this tooth being situated well forward of the termination of the main process.

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EXPLANATION OF PLATE I.

Figs. 1-2., *Oligotoma approximans* Davis, holotype ♂: 1, right fore and hindwing, x 9. 2, hind tarsus viewed laterally, x 38.

Figs. 3-4., *Notoligotoma hardyi* (Fried.), neotype ♂: 3, right forewing, x 9. 4, hind tarsus viewed laterally, x 38.

Figs. 5-7., *Oligotoma glauerti* Till., paratype ♂: 5, terminalia from above, x 9. 6, process of left hemitergite of tenth abdominal segment, from above, x 38. 7, mandibles from above, x 60.

Figs. 8-10., *Oligotoma tillyardi* Davis, holotype ♂: Corresponding structures and magnifications to Figs. 5-7.

Figs. 11-13., *Oligotoma approximans* Davis, holotype ♂: Corresponding structures and magnifications to Figs. 5-7.

Figs. 14-16., *Oligotoma gurneyi spinulosa* Davis, holotype ♂: Corresponding structures and magnifications to Figs. 5-7. (First segment of left cercus slightly distorted on slide mount, Fig. 14, LC₁).

Figs. 17-19., *Notoligotoma hardyi* (Fried.), neotype ♂: Corresponding structures and magnifications to Figs. 5-7.

(All figures prepared with a projection drawing apparatus, or based on camera lucida outlines. Setae omitted except in Figs. 2 and 4.)

9, ninth abdominal tergite; 10L, 10R, left and right hemitergites of tenth abdominal segment; LC₁, LC₂, RC₁, RC₂, first and second segments of left and right cerci respectively).

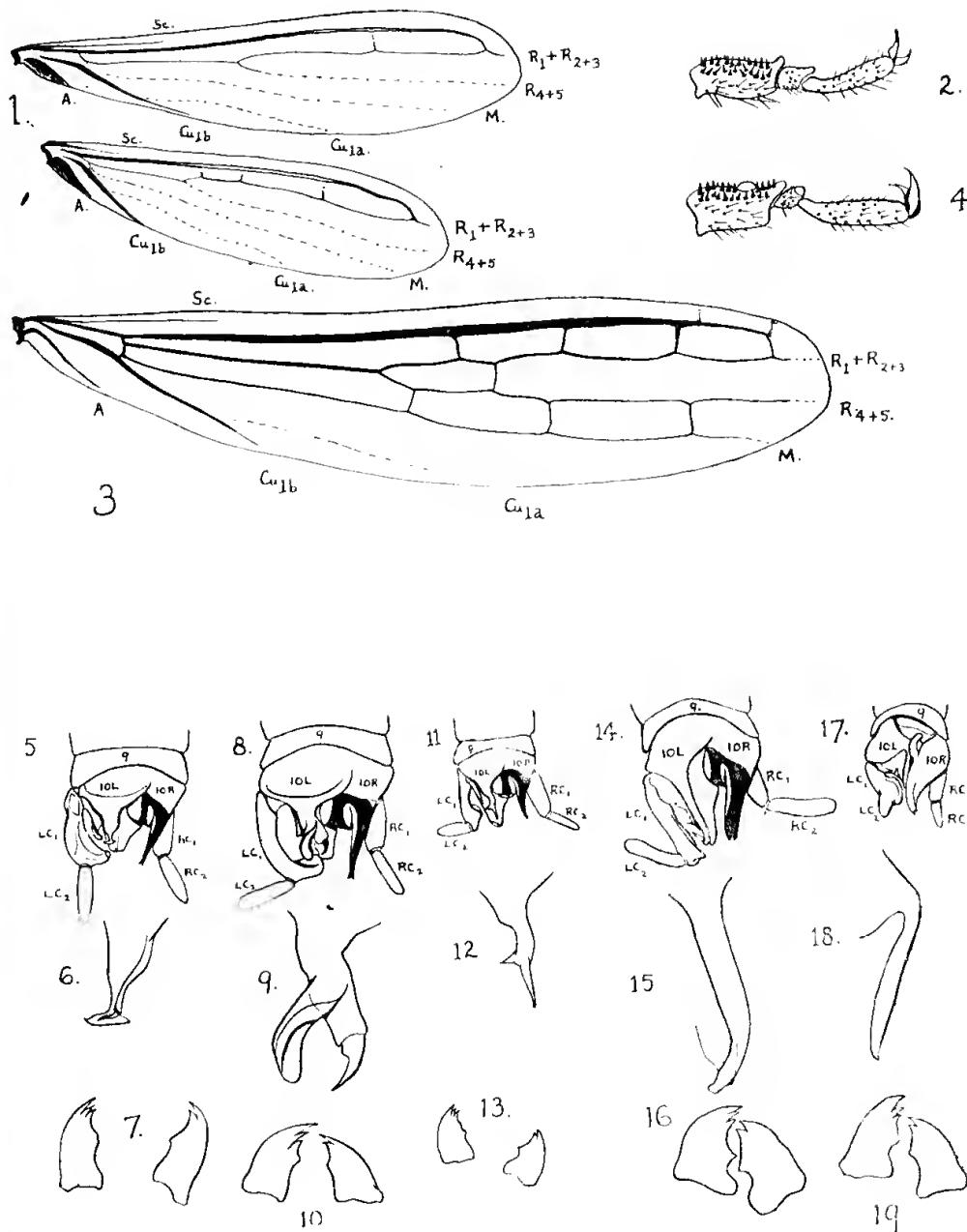


PLATE I.

6.—ECOLOGICAL SUCCESSION OBSERVED DURING REGENERATION OF *TRIODIA PUNGENS* R.BR. AFTER BURNING.

By NANCY T. BURBIDGE, B.Sc. (Hons.).

Read 10th March, 1942 : Published 6th December, 1943.

Certain investigations, into the sheep carrying capacity of the spinifex country of the north-west of Western Australia, are being carried out by officers of the Institute of Agriculture of the University of Western Australia, at Warralang Station, about sixty miles east-south-east of Port Hedland. The native spinifex is used locally for various species of *Triodia* R.Br. In the course of a taxonomic study of this genus the writer visited the country between Port Hedland and Marble Bar during the months May, June and July, 1941. Some weeks were spent at Warralang. An area of 400 acres, on this property, is being used for certain feeding experiments. The spinifex cover has been removed by burning and the plots therefore provide an excellent area for a study of regeneration. Two quadrats (20 x 20 links) were mapped in the experimental area and two (50 x 50 links) in adjacent country, which provided examples of more advanced regrowth.

The climate is semi-arid with high summer temperatures. Rain may fall at any time between December and March. The falls may be spread over some months or there may be heavy storms (willy-willies) when the average for the year may be exceeded during a twenty-four hour period. The yearly aggregates are, however, not notably variable and the climate may be described as one in which dry summers are common, but prolonged droughts rare. In 1941 a dry summer was followed, in early March, by a violent storm which caused record floods in many of the rivers.

The Warralang experimental plots are situated on the granitic plain to the south of the De Grey River. Except for an occasional ridge of stony hills due to intrusive rocks the general landscape is flat or very gently undulating. The soil is a light sandy loam, reddish in colour (Teakle, 1938).

The vegetation has been described as semi-desert savannah (Teakle i.c.). Spinifex (*Triodia* spp.) is the dominant genus. *T. pungens* R.Br. is the most important species and is frequently the only perennial grass present. Small trees and shrubs are present; their relative density varies and appears to be dependent on some soil factor which is, as yet, unrecognised.

T. pungens is the only species of the genus with real pastoral value. It is a coarse, tussock-forming, resinous grass very variable in its growth habit. At the Warralang plots the general form is a pyramidal tussock varying in size up to two metres in diameter and about the same in height.

The use of fire to improve pasture is, of course, practised in many parts of the world. Old fibrous and unpalatable material is burnt and young regrowth is more easily reached by the grazing animal. In burning spinifex it has been assumed, and indeed widely claimed, that the fire burns the tussock back to a central butt from which young shoots develop. While this is admittedly true in some places, the writer's observations showed that it is by no means always so. Over a wide area fire causes the complete destruction of the plants and regeneration takes place by means of seedling establishment.

Observations showed that along the coastal zone, from Port Hedland to the northern end of the 80-Mile Beach, burning left the tussocks with a viable butt whose regrowth was available to the grazing animal within a few months. However, through the inland country along the De Grey, Shaw and Coongan Rivers up to Marble Bar the tussocks are completely destroyed and it is at least a year before regrowth is available to the sheep. Under such conditions the risk of soil erosion is great. Fortunately the *Triodia* tussocks are fairly widely spaced (Fig. 4) and it is difficult to keep a running fire going. Thus only small patches from two or three tussocks up to about an acre are burnt in each place. The spacing of the ground cover has probably played an important role in protecting the vegetation from the consequences of biotic activities during the seventy years of pastoral occupation.

The general custom is to burn during the mustering period in April and June when the men, riding the paddocks, drop lighted matches at random. Sporadic burning is carried out at any time during the year.

It is evident that, if the tussocks are completely destroyed in May or June, the ground will lie bare until the following January or March when the summer rains bring about seedling germination. It was hoped that a study of the progress of regeneration might show whether any undesirable changes are likely to occur as a result of the burning process. That the vegetation may be altered will be shown in the discussion on succession. The alteration is a result of a combination of factors of which fire is one.

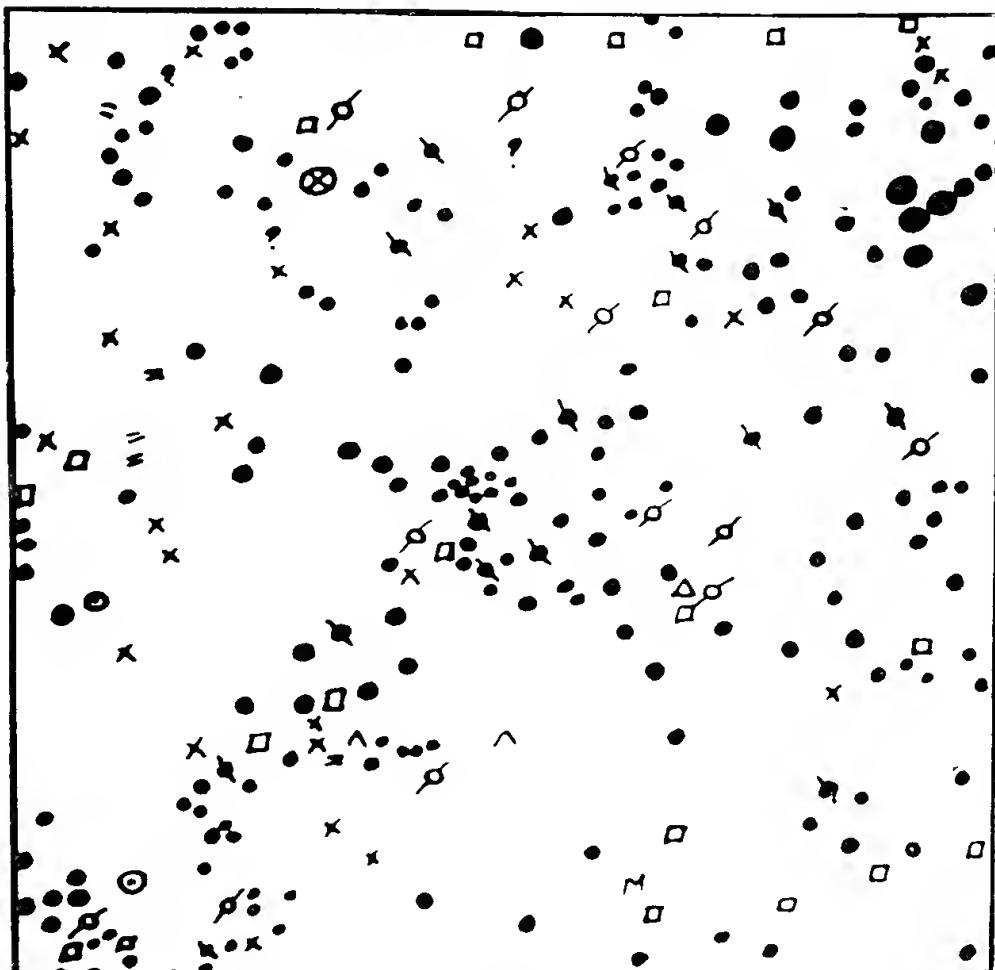


Figure 1.

QUADRATS.

Figures 1 and 2 (20×20 links = 4×4 metres), represent the primary stage in regeneration. The *Triodia* seedlings are associated with numerous annual species. The areas mapped were on the Warralóng experimental plots and the original cover was burnt off in December, 1940. Rain fell in March (willy-willy) and in April and May (light falls). The quadrats were mapped in June. It is evident that germination took place at more than one stage. The seedlings varied from 2-6 cm. in height.

The sandy loam had a scanty cover of drift sand, formerly associated with tussocks. This drift sand was disturbed by the Mareh floods. It is probable that many seeds, imbedded in the sand, were washed away. Whether this had much effect on the relative abundance of the various annual species cannot be ascertained from one season's observations. The sand drifts do, however, explain the grouping of seedlings which is evident on the maps.

In Figure 3 (50×50 links = 10×10 metres) the patch of ground represented was about a hundred yards from the experimental plots. The quadrat was surveyed in June. At this stage of regrowth there was fierce competition between the *Triodia* tussocks and ephemeral growth was meagre. In one corner an adult tussock had survived. Across another there is a patch of primary regrowth which suggests that it was burnt in the previous season.

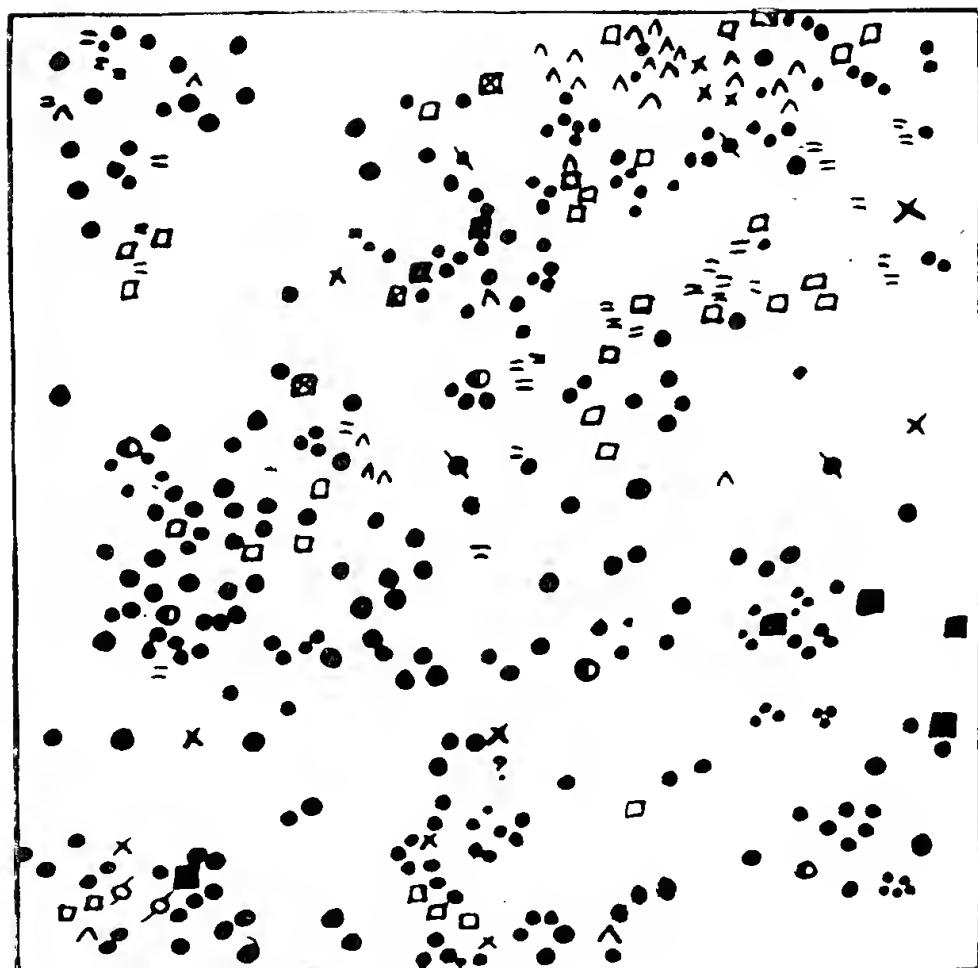


Figure 2.

It was at least two and possibly three years since the plants on the rest of the quadrat had germinated. They were about 30-40 cm. high.

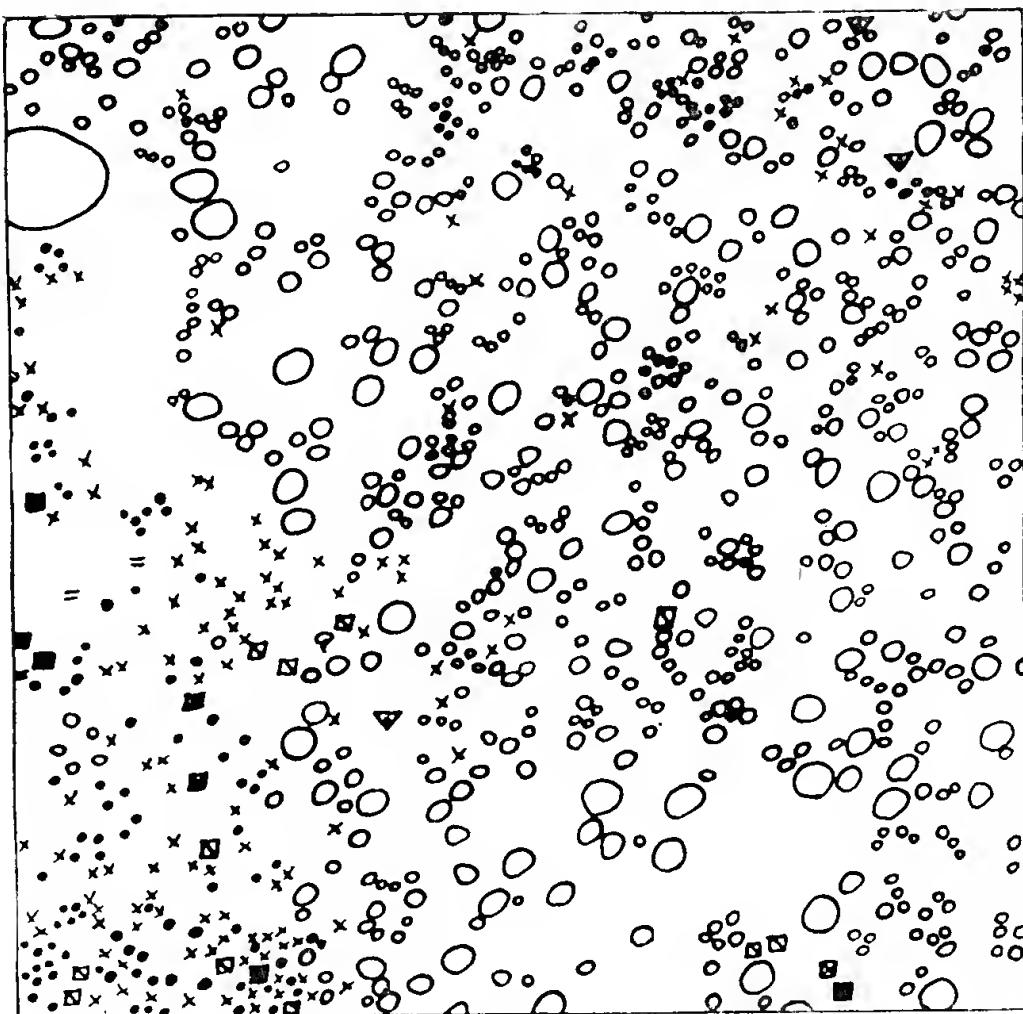


Figure 3.

In Figure 4 (50 x 50 links = 10 x 10 metres) the adult tussock stage is represented. *Triodia pungens* had established a closed community and ephemeral growth was negligible.

The quadrat was surveyed on ground about two hundred yards from the experimental plots. All ephemeral growth was dead when the mapping was done in June. Observations suggest that it was at least five years since this patch of ground had been burnt and probably much longer. The plants were about 70-100 cm. high.

Country surrounding the quadrat carried occasional plants of blood-wood (*Eucalyptus dichromophloia*), kangi (*Acacia pyrifolia*) and gema (*Carissa lanceolata*).

REGENERATION.

The germination of *Triodia* seeds is rapid after rain has sufficiently moistened the soil. The process seems to be related to soil moisture and not to any particular period of the year. However only those plants which germinate early in the year form a root system extensive enough to support it during the drought conditions of the ensuing summer months.

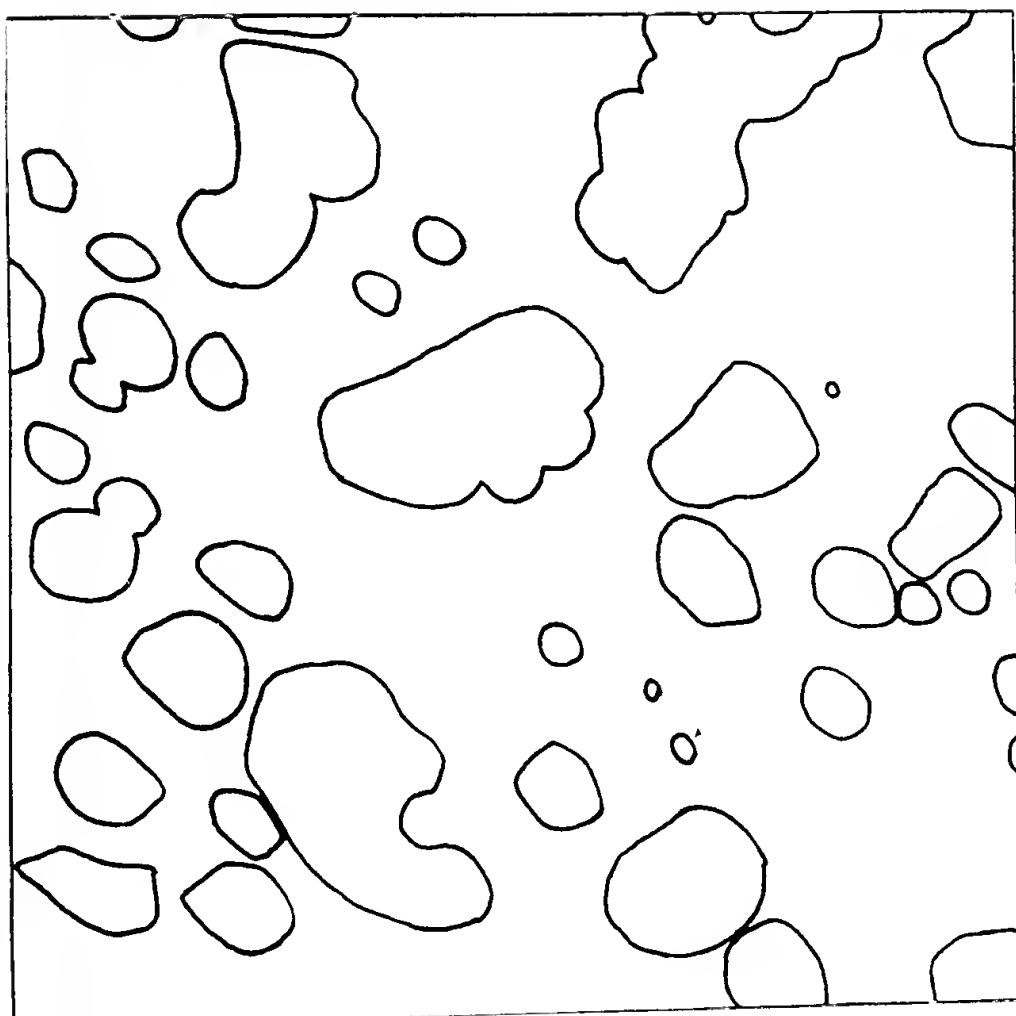


Figure 4.

The *Triodia* seedlings are soon followed by small annuals such as *Molugga molluginis*, *Euphorbia australis*, *Portulaca oleracea*, *Bulbostylis barbata*, *Eriachne pulchella*, *Aristida arenaria*, *Sporobolus australasicus*, *Eragrostis Dielsii* and *Ichnanthus australiensis*. Amongst perennials which are present at this stage the most important is *Cassia notabilis*. This species is an indicator of recent burning (within two or three years). As the plants are destroyed by termites they do not appear in older patches of spinifex. It is possible that fire improves the germination rate of this species. Other perennials which occur as occasional plants are *Solanum diversifolium*, *Sida platycalyx*, *Corchorus elachocarpus*, *Hybanthus enneaspermus*, *Eragrostis eriopoda*, *Eriachne obtusa*, *Chrysopogon pallidus* and *Neurachne Clementii*.

The areas chosen for the first two quadrats represented good regeneration. Other ground nearby varied from heavier regrowth to none at all. Regrowth appeared to be related to the water content of the soil. Areas burnt before or shortly after the March floods carried good regrowth. Those burnt later showed fewer and fewer seedlings as burning continued through the months. Those burnt in May showed no regrowth at all. There was no rain during June or July.

Apart from regeneration on burnt areas, regrowth was also to be seen on claypans wherever sand drifts formed. As a result, these bare areas

usually had an irregular formation due to patches of regrowth, in various stages of regeneration, here and there on their surface.

During the summer months following the first period of seedling development soil moisture continues to play a leading part and presumably becomes a severely limiting factor. Those seedlings whose roots have not penetrated more than the top layers of soil soon die. It is a feature of young *Triodia* seedlings that they have the most feeble attachment to the soil. It is not unusual to see a tussock 10 or 15 cm. high and about the same in diameter with only a single root holding it to the soil.

The ephemeral growth dies off very early, the majority having finished seeding by September which marks the commencement of the hot weather. The perennials, including *T. pungens*, pass into a practically dormant state.

In the second season the young tussocks compete not only with each other, but also with another crop of annuals resulting from the summer rains. These include *Polanisia icosandra*, *Aristida arenaria*, *Dactyloaenium radulans*, *Mollugo molluginis*, *Indigofera viscosa* and other species present during the first season.

By the third season the competition between the tussocks has become the dominant feature and annuals play a minor role. (Fig. 3).

As the tussocks become older many die out. Others coalesce to form compound groups. Owing to the formation of adventitious roots at many nodes, both on the ground and throughout the clump of tufts, the plants after the first year, become attached to the soil at many points within their circumference. The plants mapped in Figs. 3 and 4 all exhibited one or both of these traits.

ECOLOGICAL SUCCESSION.

The areas denuded of plant cover as a result of burning represent "secondary" bare areas, ecologically speaking, as opposed to "primary" bare areas such as those left by landslips or earthquakes.

In this case it is not essential that plants immigrate from other areas to form a new population since the soil may already contain the elements necessary for regeneration. This is so in the spinifex country since regrowth comes from seeds in the soil.

The regenerative sere may be divided into the following stages:—(i) primary stage with annuals and *Triodia* seedlings in open competition. This covers the period from germination until the rains of the following summer; (ii) secondary stage lasting more than one season, during which period the *Triodia* seedlings assume a dominant role and eliminate the annuals from the association; (iii) adult tussock stage where the *Triodia* plants have formed a closed community in which there is very little or no ephemeral growth; (iv) climax association where small trees and shrubs (which are present in a young state in (ii) and (iii)) such as *Eucalyptus dichromophloia*, *Acacia pyrifolia*, *Atalaya hemiglaeca*, *Dolichandrone heterophylla*, *Hakea lorea* (as examples of the former); and *Carissa lanceolata*, *Cassia rennusta*, *Cassia oligophylla* and *Acacia translucens* (as examples of the latter); are associated with adult tussocks.

The effect of man and his grazing animals on the association appears, so far, to have been very slight in comparison with the effect on native vegetation in other parts of the State. Nevertheless there are places, both on

Warralang and on adjoining properties, where major changes in the vegetation can be recognised. The *Triodia* on these areas has been destroyed and replaced with an *Eragrostis cripoda*-dominant association. This disturbance of the normal sequence is not merely a retrogressive change in the succession and it seems best to define it as a *disclimax*. That the disclimax is a "permanent" change is indicated by the fact that in one place the coarse woolly bases so characteristic of *Eragrostis cripoda* averaged 20 cm. in diameter. According to report this represented more than fifteen years of growth. The basic causes of the change seem to be burning followed by prolonged and heavy stocking. Whether burning was a primary cause in all cases could not be proved. In this *Eragrostis* association seedlings of *Triodia pungens* were absent and it is doubtful if they could establish themselves against the fierce competition. That the country formerly carried *Triodia pungens* is known from report and from the existence of isolated tussocks of this species among the *Eragrostis* plants. Other plants present, both ephemeral and perennial, were the same as those in a normal *Triodia pungens*-association.

In one area, on the adjoining property of Egimbah, there were indications that the *Eragrostis cripoda*-association was being removed in its turn by the grazing animal. The result was a growth of annuals in which *Mollugo molluginis*, *Aristida arenaria*, *A. hygrometrica* and *Polanisia icosandra* were the most important species. This represents a return to the condition seen in the early stages of the sere on a bare area.

SUMMARY.

Burning of *Triodia pungens* results in either the destruction of the tussock with regeneration from seedlings or a viable butt remains which sprouts again almost immediately.

In the coastal region, between Port Hedland and the northern end of the 80-Mile Beach, a viable butt is left, but inland along the Shaw, Coongan, and De Grey Rivers the tussocks are usually destroyed.

Quadrats showing stages in regeneration after burning are figured and discussed. These were mapped in or near the experimental plots at Warralang Station.

A sere is defined. The climax is one in which small trees and shrubs are associated with the dominant *Triodia pungens*. Ephemeral growth is scanty in the mature stage.

A permanent change in the vegetation, due to fire and the grazing animals, is described.

ACKNOWLEDGMENTS.

The work described in this paper was made possible by the granting of the use of certain facilities by Professor G. A. Currie and Mr. A. M. Stewart of the Institute of Agriculture, University of Western Australia. The author also wishes to express her appreciation of the hospitality of Mr. and Mrs. Frank Hardie of Warralang Station, also for assistance in the field from Mr. Frank Melville of the Institute of Agriculture.

REFERENCE.

1938, Teakle, L. J. H.: A. Regional Classification of the Soils of Western Australia. *Jour. Roy. Soc., W.A.*, Vol. 24, 1937-38.

KEY TO SYMBOLS USED IN FIGURES.

Triodia pungens seedling	..	..	●
,, tussock	..	..	○
Sporobolus australasicus	..	..	△
Eriachne pulchella	..	..	□
Ichnanthus australiensis	..	..	○△
Eragrostis eriopoda	..	..	△□
Bulbostylis barbata	..	..	==
Mollugo molluginis	..	..	✗
Portulaca oleracea	..	..	☒
Polanisia icosandra	..	..	○
Cassia notabilis	..	..	▲
Cianthus Dampieri	..	..	○☒
Euphorbia australis	..	..	△☒
Goodenia	..	..	○?
,,	?
Miscellaneous	..	..	?

7.—ECOLOGICAL NOTES ON THE VEGETATION OF 80-MILE BEACH.

By NANCY T. BURBIDGE, B.Sc. (Hons.).

Read 10th March, 1941: Published 25th February, 1944.

The area with which this paper is concerned is the portion of the coast of Western Australia between Cape Keraudren, where the No. 1 Rabbit Proof Fence reaches the coast and Cape Mississey, which marks the northern boundary of Anna Plains Station, and is the first break in the coastline of the beach. The ecological notes were obtained during a series of collecting trips through the area during July, 1941. They cover the country to a depth of from ten to fifteen miles. On an accompanying map the junction between the two main soil types is marked, since it is also the junction between the main ecological zones. The country north of Anna Plains has not been seen by the author. The vegetation of the portion of Pardoo, south of the Rabbit Proof Fence, is complicated by creeks inland and by mangrove swamps on the coast. Ecologically it is a transition region between the 80-Mile Beach and the country along the De Grey River, which is dealt with elsewhere.

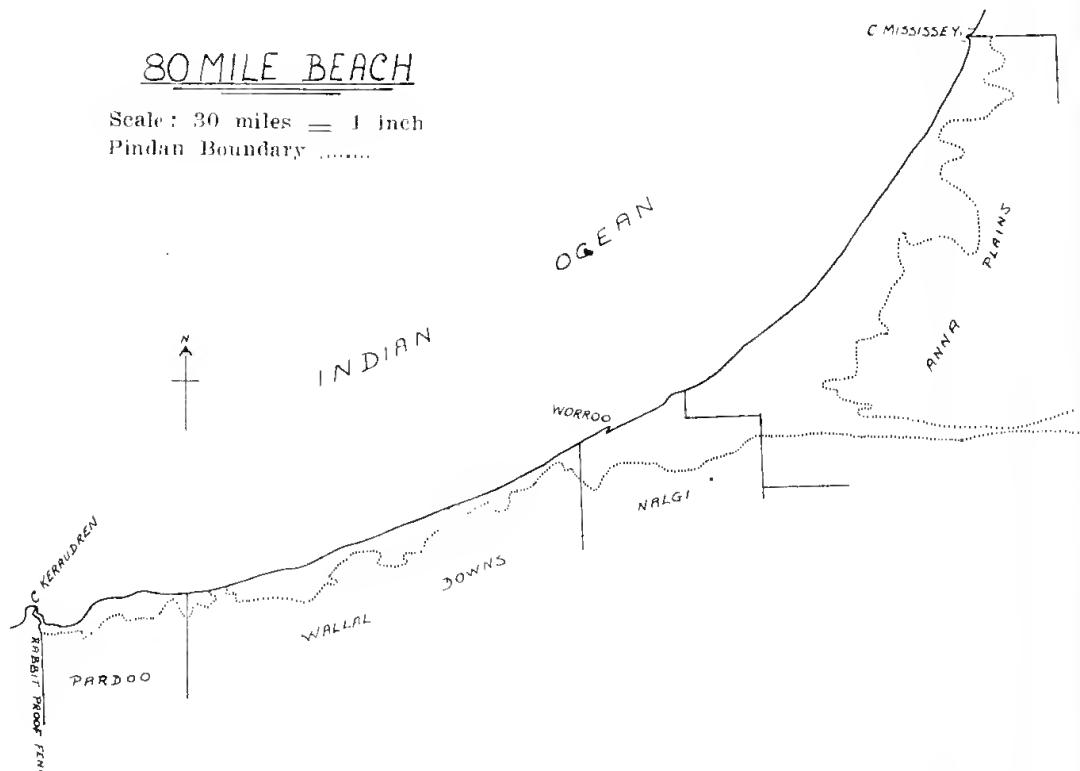
The climatic conditions are semi-arid. The annual precipitation varies between twelve and fourteen inches for the area. Most of the rain falls during the period December to March and, owing to the porous nature of the soil the water soon disappears. Permanent water holes, except for a few small native soaks, are absent. There is a marked winter drought.

PHYSIOGRAPHY AND SOILS.

The beach faces north-west or north-north-west in a long slow curve. It is without important features throughout its length. At Wooroo Creek there is a sharp but small indentation which includes a small mangrove swamp. Elsewhere the beach is unbroken. Wooroo Creek extends inland for about a mile. Behind the beach are series of sandhills varying from one to three miles in depth. The first row of the series are of normal dune type, both with and without vegetation. The sand here is very like that of the beach. Inland are sandhills carrying a different form of vegetation. The soil of these contains more organic material and is a light grey in colour compared to the creamy white beach sand. Some of the ridges have outcrops of a sandy limestone which, from the nature of its shell content, is of very recent character. Through the section included in Pardoo, Wallal, and Nalgi the sandhills dominate the coastal plain. Intermixed with them, however, are wide flats with a light grey loam soil. Through the Nalgi area these gradually increase in relative importance until in Anna Plains, where the coastal plain widens out, the loam flats are the main feature of the landscape.

The junction between the coastal plain and the spinifex pindan is marked on the map. It is a very abrupt change from the grey soils of the plain into the red desert sand. The vegetation also changes abruptly and the transitional phase occupies only a few yards. The spinifex pindan country is undulating or more or less flat with, in some places, long narrow sandhills running more or less parallel with each other and a varying distance apart. The only rock seen outcropping was a dark red ferruginous sandstone. Through Pardoo and Wallal the outcrops form small hills but on Anna Plains they result in piles of stones a few feet above the surface.

Across Nalgi and the southern section of Anna Plains is a curious tall shrub zone. The zone varies from under a mile to several miles in depth. The zone has two features worthy of comment. Firstly, just south of the Nalgi boundary is an area with numerous "blowholes" from a few inches to several feet in diameter. The depth of these is unknown. From surface indications the limestone here appears to be different in nature from that of the coastal sandhills. Secondly, through the blowhole country there are a few short drainage channels. Apart from these the whole area dealt with in this paper is entirely lacking in defined water courses.



Small patches of this shrubland occur in some places on Wallal but there is not a continuous zone as there is further north. There is no other outcrop of blowhole limestone.

Other features of interest on the coastal plain are occasional red sand ridges. The soil appears to be intermediate in character between the pindan sand and the coastal type. The former has possibly been left there as a result of wind action. East or south-east winds are of almost daily occurrence over many months of the year. Such ridges are usually near the junction of the pindan and the plain. In some cases the ridges have outcrops of the coastal sandy limestone.

ECOLOGY.

As has already been said the area may be divided into two main zones, i.e., the coastal plain and the spinifex pindan. However, the whole region belongs in the great ecological region which stretches from the Ashburton River to the Fitzroy River. This area is nearly all spinifex country, i.e., species of *Triodia* R.Br. dominate the landscape. Along the 80-Mile Beach there are just the two phases of the ecological type to discuss. *Triodia pungens* R.Br. is the dominant species and often the only grass present. Various other grasses are important in different sections but they will be

discussed under their respective headings. The trees present are stunted and often contorted in appearance. Among the shrubs various species of the Malvaceae are conspicuous. The Leguminosae, particularly in the pindan, provide a number of shrubs and small trees. These latter are mostly species of *Acacia*.

The following spectra give a picture for the area and for the two zones. It will be seen that there is a large number of annual species. This is rather misleading since the quantity of each of these is small and some species were only observed once, i.e., at the time of collecting. Another feature is that nearly all species are confined to one or other of the zones.

	Species.	No. of						E.
		M.	N.	Ch.	H.	Th.		
Whole Area . .	192	15	28	9	8	37	1	
Coastal Plain . .	65	11	12	17	9	49	—	
Spinifex Pindan	131	16	34	5	8.5	34	1	

A. Coastal Plain.

- (a) Coastal Sandhills—
 - (i) Beach dunes.
 - (ii) *Triodia* sandhills.
- (b) Loam Flats—
 - (i) Grass plains.
 - (ii) Samphire flats and claypans.
- (c) Cadgibut Shrubland.

(a) Coastal Sandhills.

(i) The beach sandhills are of the normal sand dune type, similar to those seen elsewhere along the west coast of Western Australia. Those with plant growth have a covering of *Spinifex longifolius*. Other plants include *Ipomoea biloba*, *Euphorbia myrtoides*, and *Ptilotus villosiflorus*. This association, which is often almost pure *Spinifex*, seldom occupies more than the first row of the series of sandhills along the coast.

(ii) Included under this heading are all the other sandhills of the coastal area. They include stationary sandhills of dune origin as well as those whose inner core of limestone is apparent in outcrops. As has been said above these sandhills are the main feature of the plain throughout Pardoo, Wallal and Nalgi. The vegetation is dominated by the coastal form of *Triodia pungens* which has long wiry leaves and a dense tussock habit. Near the coast there is a reed like grass, *Panicum* sp., mixed with the *Triodia*. This is less apparent further inland. There are also patches of *Acacia salicina* forming small thickets in the hollows between the sandhills.

On the ridges, where red sand has been deposited, various plants are present which, normally, are restricted to the spinifex-pindan country. These include *Bauhinia Cunninghamii*, *Acacia holosericea*, *Acacia translucens* and the form of *Triodia pungens* which is found in the desert. This last has shorter leaves and long trailing culms which are more resinous than those of the coastal form.

The general picture of the coastal plain is that of undulating sandhills with a covering of coarse tussock grasses and with small *Acacia* thickets in some of the hollows.



I. Coastal Plain showing the sharp junction with the Cadgibut Shrubland, Nalgi.

(b) Loam Flats.

(i) The grass plains are relatively unimportant until the Anna Plains country is reached. Elsewhere only odd patches occur between the sandhills. Also over a good deal of the area the native grasses have been replaced by the introduced species *Cenchrus ciliaris* (Buffel Grass). Most of the notes concerning the native grasses were made at Anna Plains where the flats have been grazed by cattle for some years. Whether there has been any floristic alteration as a result of the grazing it is not possible to say on the available information.

Triodia pungens is lacking from the loam soils. The grassland is a mixture of species and it would be difficult to say which is the most important. Species which do occur are *Eragrostis Dielsii*, *E. lacunaria*, *Xerochloa barbata*, *Enneapogon planifolius*, *Sporobolus actinocladus*, *Triraphis mollis*, *Dichanthium humilius*, *Chloris ruderalis*, *Panicum decompositum* var. *seaberriimum* and also *Sporobolus virginicus* which has two growth forms. As Salt Grass it forms a coarse mat 8-12 inches thick of erect culms while as Coastal Couch grass it has long trailing culms often more than twelve feet in length. The two forms appear to be the result of a response to a slight alteration in soil mineral salt content.

On what appear to be damper patches in the grassland there are colonies of *Eulalia fulva* or *Bothriochloa decipiens* (both known as Bundle Bundle Grass) with *Panicum decompositum* as a subordinant form.

As a rule the grass flats are treeless areas but occasionally there are small groups of *Melaleuca leucadendron* and *M. lasiandra* (Cadgibut). Here, as a rule, most of the grasses are absent, though *Cenchrus ciliaris* may occur. These tree groups represent isolated patches of the Cadgibut shrubland facies which forms a definite phase in the transitional zone between the coastal plain vegetation and that of the spinifex pindan. This border type appears not only where the junction is between loam and red sand but also where it is between grey and red sand.

(ii) Samphire flats and claypans occur in the sand hill country as well as on the grass flats. The soil is grey loam. Since there is no proper drainage system the loam flats are the only places where one would expect water to lie after rain. Tracks through these flats have a sinister reputation for their mud during the wet season. It seems likely that the soil here has a slightly higher concentration of mineral salts. If this is so it explains the zonation which can be observed. There are three zones. In the outer one *Sporobolus virginicus* (Salt Grass form) is dominant and there may be colonies of *Trianthema turgidifolia*. Other plants which have been collected in this zone include *Trichinium exaltatum* and *Scaevola spinescens*. In the next zone *Trianthema turgidifolia* has become dominant. Mixed with it are *Bassia astrocarpa* and *Atriplex clachophylla*. In some places either of these zones may carry small thickets of *Acacia bivenosa* or *Acacia salicina*, but otherwise trees and shrubs are completely lacking on the samphire flats. *Trianthema turgidifolia* is locally known as yellow samphire. The third zone sees *Trianthema turgidifolia* replaced by *Arthrocnemum Benthamii* (Red or Black Samphire). This species gradually thins out until the bare ground of the centre is reached.

A good example of samphire flat is seen at Wooroo Creek between the sandhills. The portion near the creek, which has a border of mangroves, is flooded at certain times of the year when there are exceptionally high tides. Over this portion *Trianthema* is replaced by *Arthrocnemum Benthamii*.

(e) Cadgibut Shrubland.

This section represents a peculiar development of the coastal plain. Various species of *Melaleuca* are abundant and dominate the vegetation. This is in striking contrast to the almost treeless plain. The soil is grey loam as on the flats. The species of *Melaleuca* present are *M. leucadendron*, *M. alsophila* and *M. lasiandra*. This association is found along the Nalgi frontage between the plain and the spinifex pindan. In the southern section of Anna Plains it turns eastwards and is lost in the desert. On Wallal isolated patches of similar country are found in a similar situation, but there is no distinct sub-zone.

Apart from the *Melaleuca* trees (up to 15 feet high) the vegetation is very much the same as on the samphire flats. However occasional patches of *Triodia pungens* of the plains form are to be seen, especially where small sand drifts have formed under the trees. The local impression was that *Trianthema turgidifolia* had replaced *Sporobolus virginicus* during the grazing of the years of occupation. However, since the former can withstand

higher concentrations of mineral salts, one must hesitate before placing all the responsibility of such a change on to the biotic factor. It is equally possible that climatic cycles may be an important factor.

In the northern part of the shrubland eadgibuts are replaced by *Acacia salicina* and *Acacia bivenosa*. Small drainage channels in this country are bare of vegetation and meander through the samphire for a mile or so.

Throughout this shrubland stock water can be obtained at no great depth. Wooroo Well on the Stock Route and about three miles inland from Wooroo Creek is an example. When visited in July the water level in this well was about twelve feet from the surface. This well is on the site of an old aboriginal soak. Other wells in the zone vary in depth but no figures are available. On the coastal plain, ground water is commonly too salt for stock while in the spinifex country the water though deeper down is, in most cases, classed as "good stock water."

B. *Spinifex Pindan.*

The name "spinifex" is used locally for all species of *Triodia*; "pindan" is a native word which is used for the desert country by the pastoralists. This zone can be subdivided as follows:—

- (a) Transitional phase
- (b) *Triodia* phase.
- (c) *Plectrachne* phase.

(a) The transitional phase is particularly clear along the Anna Plains frontage. It commences with a line of *Melaleuca* trees on the edge of the treeless grey loam plain. The ground flora includes small annuals such as *Sporobolus australasicus* and *Eragrostis Dielsii* with occasional bushes of *Trianthema turgidifolia*. Where the loam changes to the red sand the flora also changes and *Eragrostis eriopoda*, *Crotalaria Cunninghamii*, and *Polygonia icosandra* replace the above mentioned species. This phase gives way to a dense zone of *Melaleuca lasiandra* and *Acacia translucens*, which are both shrubs about three to five feet high, with occasional clumps of *Triodia pungens* and *Eragrostis eriopoda*. After this the eadgibuts disappear and the area can no longer be classed as transitional.

There are certain variations of the transitional phase. In some places there is a band of *Acacia salicina* in others the *Acacia translucens* band is missing. The change-over is narrow and the transitional phase may only be ten or 15 yards in depth. In other places it extends up to 50 but this is not often.

(b) and (c) The spinifex pindan has two definite phases. In the first the pindan form of *Triodia pungens* is associated with a stunted form of *Bauhinia Cunninghamii*. In the second *Triodia* is replaced by a similar grass *Plectrachne Schinzii* and *Bauhinia* is replaced by small trees such as *Dolichandrone heterophylla* and *Eucalyptus zygophylla*.

The first of these phases is the nearer to the coast. Its inland boundary is not very definite and the phase varies in depth. The *Plectrachne* country apparently runs out into the desert proper. It extended inland as far as the author travelled, i.e., to a distance of fifteen miles from the coast at Wallal. According to report it extends along the Rabbit Proof Fence at least as far as the 121 degree meridian.



II. Spinifex pindan showing the association of shrubs and tussock grasses. *Acacia holosericea*, *A. tumida* and *Plectrachne Schinzii*.

Both phases of the pindan carry various species of *Acacia*. These, except in the case of *Acacia transluens* which grows about two to three feet high, are all small trees. They commonly form thickets in which only one species is represented. The commoner species are *A. tumida*, *A. holosericea*, *A. trachycarpa*, *A. pachycarpa*, *A. coriacea*, *A. impressa* and *A. stipuligera*.

In marked contrast to the coastal plain are the number of shrubs which are associated with the perennial tussock grasses. They include the following: *Abutilon Walcottii*, *A. indicum*, *Sida lepida*, *S. spinosa*, *Calythrix interstans*, *Halgania littoralis*, *Pimelea ammocharis*, *Adriana tomentosa*, *Cyanostegia Bunnyana*, and *Newcastlia cladotricha*. Larger forms are *Cassia glutinosa*, *C. Sturtii* var., *Clerodendron tomentosum*, *Gardenia Pantoni* and *Duboisia Hopwoodii* and *Stylobasium spathulatum*. Members of the Proteaceae are not numerically important. They include *Grevillea pyramidalis*, *G. refracta*, *G. agrifolia*, *Hakea macrocarpa* and *Persoonia falcata*. There are many slender shrubs belonging to the Leguminosae. Eucalypts are not well represented. In most places they are completely lacking from the *Triodia* phase while in the *Plectrachne* country they gradually appear more often as one goes farther inland. They either form small mallee clumps or develop into small trees from ten to fifteen feet high. The species are *Eucalyptus zygophylla* and *E. dichromophloia*.

Plants of *Eragrostis eriopoda* are often seen amongst the *Triodia* tussocks. This grass is the most important species after *Triodia* and *Plectrachne* since it replaces both when they are destroyed and prevented from recovering through seedling development. Normally *Eragrostis eriopoda* is present in the association as a minor constituent.

Other grasses present are *Amphipogon strictus*, *Chrysopogon pallidus*, *Cymbopogon bombycinus*, *Digitaria Brownei*, *Digitaria ctenantha*, *Panicum cymbiforme*, *Ichnanthus australiensis*, *Setaria surgens*, *Aristida arenaria*,

Enneapogon pallidus, *Eriachne pulchella* and *Sorghum plumosum*. None of these grasses is an important constituent.

The further one penetrates into the desert the more numerous become the long sand ridges. These, presumably, are similar to those described by Warburton (1875) and Carnegie (1898) in the country to the east. General observations suggested that the *Acacia* thickets grew between the ridges or in open country while small plants of *Bauhinia Cunninghamii* and small trees such as *Owenia retinervata* and *Hakea macrocarpa* grew on the ridges.

SUMMARY.

An attempt has been made to describe the vegetation of the coastal strip between Cape Keraudren and Cape Mississey. It has been shown that there are two well defined ecological zones which are associated with certain soil differences.

On the coastal plain the biotic factor has been responsible for the introduction of *Cenchrus ciliaris* (Buffel Grass) especially on loamy soils. In the desert country no introduced plant has as yet succeeded in establishing itself but where the normal tussock grasses are lost they are replaced by the native species *Eragrostis eriopoda*.

ACKNOWLEDGMENTS.

The author wishes to express her thanks for assistance given by the following: Mr. S. Millins of Anna Plains Station, Mr. Spry of Nalgi Station, Mr. Lacy of Wallal Downs Station and Mr. Welch of Pardoo Station. Without the co-operation of these the work could not have been carried out.

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Carnegie, D. W.: Spinifex and Sand 1898.
Warburton, P. E.: Journey Across the Western Interior of Australia: 1875.

8.—BRYOZOA FROM THE WANDAGEE AND NOONCANBAH SERIES (PERMIAN) OF WESTERN AUSTRALIA.

PART ONE.

By JOAN CROCKFORD, M.Sc.

Read 14th April, 1942: Published 24th March, 1944.

Communicated by Professor E. de C. Clarke.

CONTENTS.

	Page.
Summary	165
Introduction	165
Description of Species:—	
Family Fenestrellinidae Bassler.	
Genus <i>Fenestrellina</i> d'Orbigny.	
<i>Fenestrellina horologia</i> (Bretnall)	167
<i>Fenestrellina disjecta</i> sp. nov.	168
<i>Fenestrellina ruidacarinata</i> sp. nov.	169
<i>Fenestrellina valentis</i> sp. nov.	169
<i>Fenestrellina columnaris</i> sp. nov.	170
<i>Fenestrellina lennardi</i> sp. nov.	171
<i>Fenestrellina cacuminalis</i> sp. nov.	171
Genus <i>Minilya</i> gen. nov.	
<i>Minilya duplaris</i> sp. nov.	173
<i>Minilya princeps</i> sp. nov.	174
Genus <i>Polypora</i> McCoy.	
<i>Polypora forea</i> sp. nov.	175
<i>Polypora retificis</i> sp. nov.	176
<i>Polypora woodsi</i> (Etheridge)	177
<i>Polypora multiporifera</i> sp. nov.	177
<i>Polypora</i> sp. nov. indet.	178
Acknowledgments	179
Bibliography	179

SUMMARY.

Fourteen species of Fenestrellinidae (*Fenestrellina* and *Polypora*), of which twelve are described as new, and one new genus allied to *Fenestrellina*, are described from the Wandagee Series of the North-West Basin and the Nooncanbah Series of the Kimberley District (Permian) of Western Australia.

INTRODUCTION.

Bryozoa from the Permian and Carboniferous of Western Australia were first recorded by Hudleston in 1883, when he described *Evactinopora dendroidea* Hudleston and *E. crucialis* Hudleston, and recorded *Fenestellae*, *Fenestella plebia* McCoy, *Protoretipora* (sic) (*Fenestella*) *ampla* Lonsdale var., and *Stenopora tasmaniensis* Lonsdale from the "Carboniferous" North of the Gascoyne River. *Fenestella* ("probably *F. ampla*") was recorded by Foord (1890) from the Irwin River; Hinde, in 1890, recorded *Hexagonella dendroidea* (Hudleston), and described *Polypora australis* Hinde and *Rhombopora tenuis* Hinde from the "Carboniferous" of the Gascoyne River District.

R. Etheridge jnr. recorded *Stenopora* and *Evactinopora* from Mt. Marmion (1889); *Hexagonella dendroidea* and *H. (?) crucialis* from Fossil Hill, Wyndham River (1903); *Fenestella fossula* Lonsdale from the Irwin River (1907); and *Evactinopora crucialis* and two types of *Stenopora* (*Stenopora* spp. A and C) from Mt. Marmion, and *Stenopora* sp. B from near Barabiddie (1915). Chapman (1904) recorded *Stenopora leichardtii* Nicholson and Etheridge jnr. from the Irwin River District.

Bretnall (1926) described *Lyropora* (?) *erkosoides* Etheridge ms., *Fenestella horologia* Bretnall, *F. affluensa* Bretnall, *Sulcoretepora* (?) *meridianus* Etheridge ms., *Aetomocladia ambrosoides* Bretnall, *Streblotrypa marmionensis* Etheridge ms., *S. etheridgei* Bretnall, *Rhombopora mamillata* Bretnall, *R. multigranulata* Bretnall, and *Cosecium* (?) *australe* Bretnall, and recorded *Rhombopora tenuis* Hinde, from the Permo-Carboniferous of the Gascoyne and Kimberley Districts. Miss L. Hosking (1931) recorded *Aetomocladia ambrosoides*, *Cosecium* (?) sp., *Fenestella affluensa*, *F. horologia*, *Rhombopora mamillata*, *R. multigranulata*, *Streblotrypa marmionensis*, and *Sulcoretepora meridianus* from the Wooramel River District.

Etheridge (1907 a) described some Permo-Carboniferous bryozoa from the Port Keats Bore, thirty miles north of Fossil Head, Victoria River estuary, Northern Territory, and discussed their relationships to Western Australian forms.

Gibb Maitland (1909), Raggatt (1936), and Condit, Raggatt, and Rudd (1936), have published lists of fossils, including bryozoa, from the Permo-Carboniferous of the North-West District, and Blatchford (1927) and Wade (1937) from the Permo-Carboniferous of the Kimberley District.

The stratigraphical position of the Wandagee Series has been discussed by Condit (1935), Condit, Raggatt, and Rudd (1936), Raggatt (1936), and Teichert (1939, 1940, 1941); and the position of the Nooneanbah Series by Wade (1937) and Teichert (1940, 1941).

The bryozoa described here are from the Wandagee Series of the North-West Basin, and from the Nooneanbah Series of the Kimberley District. Fourteen species are recorded, and of these seven are known only from the Nooneanbah Series, and two only from the Wandagee Series. The distribution of the species is given in Table I, and a comparison of their measurements in Table II.

Discussion of the age and affinities of the bryozoan fauna of the Wandagee and Nooneanbah Series is left until a later paper.

DESCRIPTION OF SPECIES.

Phylum BRYOZOA Ehrenberg.

Class GYMNOLEMATA Allman.

Order CRYPTOSTOMATA Vine.

Family FENESTRELLINIDAE Bassler.

Genus FENESTRELLINA* d'Orbigny.

Fenestrellina d'Orbigny, 1849, *Revue et Magasin de Zoologie*, 2^e Ser., Tome I, p. 501.

Homonym:—*Fenestella* Lonsdale, 1839, preoccupied for a pelecypod, *Fenestella* Bolten, 1798.

* An application for suspension of the Rules of Zoological Nomenclature for the generic name *Fenestella* Lonsdale, 1839, has been submitted to the International Commission on Zoological Nomenclature (G. E. Condra and M. K. Elias, *Journal of Paleontology*, Vol. 15, No. 4, pp. 565-566).

BRYOZOA FROM THE WANDAGEE AND NOONCANBAH SERIES
(PERMIAN) OF WESTERN AUSTRALIA.

TABLE I. DISTRIBUTION OF SPECIES DESCRIBED.

	Wandagee Series.					Nooncanbah Series.					Other Localities.		
	Calceolisporgia Stage.					Linoprotectus Stage.							
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
<i>Fenestrellina horologia</i> (Bretnall)						-		-	-	-	-	-	-
<i>Fenestrellina disjecta</i> sp. nov. ...									-	-	-	-	-
<i>Fenestrellina ruidacarinata</i> sp. nov.									-	-	-	-	-
<i>Fenestrellina ralentis</i> sp. nov. ...									-	-	-	-	-
<i>Fenestrellina columnaris</i> sp. nov.													
<i>Fenestrellina lennardi</i> sp. nov. ...												-	A.
<i>Fenestrellina cuminumatis</i> sp. nov.													
<i>Minilya duplaria</i> sp. nov. ...									-	-	-	-	A.
<i>Minilya priaceps</i> sp. nov. ...									-	-	-	-	-
<i>Polypora forta</i> sp. nov. ...									-	-	-	-	-
<i>Polypora reticulata</i> sp. nov. ...									-	-	-	-	-
<i>Polypora woodsi</i> (Etheridge) ...									-	-	-	-	-
<i>Polypora multiporifera</i> sp. nov. ...						-							
<i>Polypora</i> sp. nov. indet. ...									-	-	-	-	-

1. Lower sandy part of the Calceolisporgia Stage, South side of Minilya River, 1½ to 2 miles East-North-East from Cindanunda Well, Wandagee Station.
2. Lower half of the Calceolisporgia Stage, ½ mile West of Coolkilya Pool.
3. Locality W.
4. Syncline on Minilya River, ½ mile West of Coolkilya Pool.
5. Uppermost part of the Calceolisporgia Stage, North side of Minilya River, 1 mile West of Coolkilya Pool.
6. Lowest bed of Linoprotectus Stage, East-West striking fault block, North-West of North end of Wandagee Hill, on Telephone Line, just inside Woollies Paddock, Wandagee Station.

7. 28 chains North-East of Flag Station 12, Nalbia Paddock, Wandagee Station.
8. Highest Pseudogastrioceras horizon, 300 yds. East of South-West gully of Wandagee Hill, Mungadah Paddock, Wandagee Station.
9. Scarp 2 miles East of Christmas Ck, Homestead.
10. 9 miles East-North-East of Trig. Station G2, St. George's Range, Kimberley District.
11. 6½ miles North of Mt. Anderson, Kimberley District.
12. Keevie's Well, 8 miles North of Mt. Anderson Homestead, Kimberley District.
13. Mt. Marmion, Kimberley District; A: Highest Beds of Nooncanbah Series, S. side of Mt. Marmion; B: Mt. Marmion (F17547, Australian Museum Coll.)



BRYOZOA FROM THE WANDAGEE AND NOONCANBAH SERIES
(PERMIAN) OF WESTERN AUSTRALIA.

TABLE II.—MEASUREMENTS OF SPECIES DESCRIBED.

Species.	Locality.	Branches.		Fenestrales.		Width of Dissepiment (mm.).	Zooecia.			Nodes.
		No. in 10 mm.	Width (mm.).	No. in 10 mm.	Length (mm.).		No. of Rows.	No. in 10 mm.	No. per Fenestrile.	
<i>Fenestrellina horologia</i> (Brettnall)	8 miles North of Mt. Anderson Homestead	20-22	0.29-0.38	16-18	0.29-0.52	0.1-0.29	2	37	2	High, in a single row, 0.23-0.31 mm. apart.
<i>Fenestrellina disjecta</i> sp. nov. ...	6½ miles North of Mt. Anderson	12	0.33-0.4	10	0.7-0.94	0.14-0.24	2	40	4-5	Very high, elongated, 0.98-1.17 mm. apart.
<i>Fenestrellina raidacarinata</i> sp. nov.	9 miles East-North-East from Trig. Stn. G2, St. George's Ra.	16	0.33-0.38	10-10.5	0.6-0.75	0.21-0.27	2	38	3-4	Rounded, contiguous, 0.13-0.22 mm. apart.
<i>Fenestrellina valentis</i> sp. nov. ...	6½ miles North of Mt. Anderson	40	0.63-0.75	10	0.52-0.68	0.4-0.48	2	33	3-4	Small, rather rounded, 0.24-0.4 mm. apart.
<i>Fenestrellina columnaris</i> sp. nov.	½ mile West of Coolkilya Pool, Minilya River	16	0.33-0.38	14-15	0.44-0.5	0.22-0.3	2	37	3	High, thick, blunt, 0.33-0.4 mm. apart.
<i>Fenestrellina leonardi</i> sp. nov. ...	South side of Mt. Marmion	22	0.24-0.32	31	0.17-0.25	about 0.1	2	31	1	Small, not well shown.
<i>Fenestrellina carminatis</i> sp. nov.	8 miles North of Mt. Anderson Homestead	22	0.25	44	0.52-0.63	about 0.12	2	42	3	Small, sharp, 0.24-0.29 mm. apart.
<i>Minilya duplaria</i> sp. nov. ...	6½ miles North of Mt. Anderson	16-19	0.33-0.41	14-17	0.4-0.51	0.11-0.3	2	33	2	Small, in two rows, 0.13-0.17 mm. apart.
<i>Minilya pinniceps</i> sp. nov. ...	8 miles North of Mt. Anderson Homestead	17	0.41-0.48	10-10.5	0.57-0.62	0.32-0.36	2	28	3	Small, in two rows, 0.13-0.21 mm. apart.
<i>Polypora foeca</i> sp. nov. ...	8 miles North of Mt. Anderson Homestead	8-12	0.45-0.7	6-6.5	1.15-1.36	0.17-0.29	4-5	31	4-5	Small, irregularly developed.
<i>Polypora reticulata</i> sp. nov. ...	½ mile West of Coolkilya Pool, Minilya River	15-17	0.48-0.57	9	0.67-0.8	0.41-0.6	3	33	4	Large, irregularly placed.
<i>Polypora woodsi</i> (Etheridge) ...	8 miles North of Mt. Anderson Homestead	10-11	0.52-0.62	8	0.68-0.92	0.46-0.63	3	31	4	Abundant, regularly placed, rather large.
<i>Polypora multiporifera</i> sp. nov. ...	½ mile West of Coolkilya Pool, Minilya River	5	0.97-1.1	1.5-2.5	2.1-5.6	0.46-0.6	5-6	22	6-14	Small, rather abundant.
<i>Polypora</i> sp. nov. indet. ...	Scarp 2 miles East of Christmas Ck. Homestead	3-4	1.2-1.55	1.5-2	3.3-6.9	1.2-1.6	about 8	?	9-15	? Not developed.



Infundibuliform or flabellate Fenestrellinidae, with two rows of alternating zooceria on the branches, except before bifurcation, when the number of rows is increased; rows of zooceria separated by a medium carina, plain or more frequently with a single row of nodes (acanthopores); dissepiments not celluliferous; internal structure and reverse surface as for the family.

Fenestrellina horologia (Bretmell).* (Plate 1, figs. 3, 6.)

Fenestella horologia Bretmell, 1926, descriptions of some Western Australian Fossil Polyzoa, W.A. Geol. Surv. Bull. 88, p. 15, pl. 1, fig. 6.

[non] *Fenestella horologia* Bretmell, Hosking, 1931, Fossils from the Woormel District, W.A., Jour. Roy. Soc., W.A., Vol. XVII., p. 13, pl. IV., fig. 3.

Fenestella parvinscula Bassler, 1929, Permian Bryozoa of Timor, *Palaeontologie von Timor*, Lief. XVI., XXVIII., p. 76, pl. CCXL (47), figs. 8-13.

Fenestella parvinscula Bassler, Martin, 1932, De Paleontologie en Stratigraphie van Nederlandsch Oost-Indie, Bryozoa, p. 391.

Fenestella parvinscula Bassler, Fritz, 1932, Permian Bryozoa from Vancouver Island, Trans. Roy. Soc., Canada, Ser. 3, Vol. 26, Sect. IV., p. 99.

Fenestrellina parvinscula (Bassler), Elias, 1937, Stratigraphic Significance of Some Late Paleozoic Fenestrate Bryozoans, Jour. Paleontology, Vol. 11, No. 4, p. 314.

Fenestrellina with two zooceria to a fenestrule; carina low; nodes sharp, relatively high, about two to a fenestrule; fenestrules hour-glass shaped.

Horizon and locality: Nooncambah Series; Keevie's Well, eight miles north of Mt. Anderson Homestead, Kimberley District (Coll. A. Wade).

The form of the colony is not shown; there are from 16 to 18 fenestrules vertically, and from 20 to 22 branches horizontally, in 10 mm. The branches are straight, from 0.29 to 0.38 mm. in width, and show a slight, rather rounded carina, with sharp, relatively high nodes in a single row, at intervals of from 0.23 to 0.31 mm.; the bases of these nodes are slightly elongated parallel to the length of the branches. In the older parts of the colony supporting rootlets may be developed from the celluliferous surface, and the thickness of the branches (normally about 0.3 mm.) may be greatly increased by extra deposits of calcium carbonate; the nodes become very much thickened, and may appear bifid or trifid near the top, and the apertures become closed. The sides of the branches, on which the apertures are placed, are slightly flattened, but the apertures project into the fenestrules; they are circular, from 0.1 to 0.13 mm. in diameter, and where they are well preserved show about eight fine radially directed ribs; these, however, were very easily removed by weathering; the peristomes are distinct, and are best developed on the side towards the fenestrules. Two apertures occur in the length of one fenestrule and one dissepiment; these are usually very regularly arranged, one being placed opposite the end of each dissepiment, and one at the centre of each fenestrule—the projection of these apertures into the fenestrules gives them their characteristic hour-glass shape; a less regular arrangement may be developed for a few fenestrules. The distance between the centres of successive apertures is from 0.21 to 0.34 mm. (average 0.27 mm.), but is generally between 0.25 and

* This species is being revised, in a separate paper, from the type material in the collection of the Western Australian Geological Survey, with which the specimens here described have been compared.

0.3 mm.; about thirty-seven apertures occur in 10 mm. The fenestrules are from 0.29 to 0.52 mm. in length and from 0.17 to 0.4 mm. in width; the width of the dissepiments is from 0.1 to 0.29 mm., but is generally less than 0.2 mm., and the length of one fenestrule and one dissepiment is from 0.49 to 0.65 mm. (average 0.57 mm.). The dissepiments, where they are well-preserved, may show two or more fine transverse ridges, and the whole of the celluliferous surface is covered by very fine tubercles. On the reverse surface both branches and dissepiments are evenly rounded, and the dissepiments may be as thick as the branches; the outermost layer is finely granular, and the backs of the branches may be ornamented by fine nodes, though these are not always developed over the whole of the reverse surface, and are easily worn away. The inner layers of the reverse surface show fine longitudinal striae. Bifurcation occurs usually at distant intervals, though it may be frequent: increase to the three rows of zoocia occurs immediately before branching.

Remarks: *Fenestrellina horologia* was described by Bretnall from the Gaseyne River District; it occurs as low in the Permo-Carboniferous as the Callytharra Stage; and occurs also in Queensland (Consuelo Ck., two miles above Cattle Creek, Springsure District; Reid, 1930, p. 157, locality 9). It appears to be the same as *Fenestrellina parviuscula* (Bassler), which occurs in Timor in both the Bitaoeni and Basleo beds. *F. parviuscula* has also been recorded from the Permian of Vancouver Island.

***Fenestrellina disjecta* sp. nov.**

Plate 1, Fig. 2; Text-figure 1 E.

Holotype: Specimen 2793a, University of Western Australia Collection. (Coll. H. W. B. Talbot.)

Horizon and locality: Nooncanbah Series; 6½ m. North of Mt. Anderson.

Fenestrellina with four to five zoocia to a fenestrule; slight carina; very high nodes, one occurring in the length of each fenestrule, and usually placed opposite the junction of a branch and a dissepiment.

The form of the colony is not shown; there are 12 branches horizontally, and 10 fenestrules vertically, in 10 mm. The branches are straight, from 0.33 to 0.4 mm. in width, and show a slight median carina, bounded by a depression on each side. Very high nodes, with their bases elongated parallel to the length of the branches, occur at intervals of from 0.98 to 1.17 mm., and are generally placed opposite the junction of a dissepiment with a branch; in well preserved specimens the height of these nodes is up to 0.25 mm., but they usually appear very much smaller. The apertures are circular, 0.08 mm. in diameter, and are surrounded by distinct peristomes. Four, less often five, apertures occur in the length of one fenestrule and one dissepiment; the distance between the centres of successive apertures is from 0.21 to 0.28 mm. (average 0.25 mm.) and about forty apertures occur in 10 mm. The fenestrules are oval, from 0.7 to 0.94 mm. in length, and from 0.29 to 0.54 mm. in width; the dissepiments are from 0.14 to 0.24 mm. in width, and the length of one fenestrule and one dissepiment is from 0.89 to 1.16 mm. On the celluliferous surface the dissepiments are slightly rounded and show four or five fine transverse ridges and grooves. On the reverse surface both branches and dissepiments show numerous fine longitudinal striae where they are slightly weathered. The dissepiments are distinctly thinner than the branches. At their junction with the dissepiments

the branches show fairly large, rather indistinct tubercles on the reverse surface. The lateral margins of each branch are angular. Bifurcation may occur at intervals of about 4 mm., but is usually much less frequent; increase to three rows of zoocia occurs immediately before branching.

Remarks: This species is distinguished from described species of similar size by its large, widely spaced nodes.

Fenestrellina ruidacarinata sp. nov.

Plate 2. Figs. 1, 2.

Holotype: Specimen 2757a, University of Western Australia Collection. (Coll. H. W. B. Talbot).

Horizon and locality: Nooncanbah Series; 9 m. E.N.E. from Trig. Stn. G2, St. George's Range.

Fenestrellina with three to four zoocia to a fenestrula; carina low, nodes rounded, contiguous, five to six in the length of each fenestrula.

The form of the colony is not shown; there are 16 branches horizontally, and 10 to 10.5 fenestrules vertically, in 10 mm. The branches are straight, and are rather rounded on the celluliferous surface; the apertures are placed on the sloping sides of the branches, but do not project into the fenestrules; the width of the branches is from 0.33 to 0.38 mm. The carina is almost obsolete, and is completely covered by the nodes, which are low, rounded, and contiguous, and which vary in diameter, though they do not vary in height, except as a result of weathering, which may remove all traces of the divisions between adjacent nodes and leave only a slight ridge along the centre of the branch. Five to six nodes occur in the length of each fenestrula; the distance between the centres of successive nodes is from 0.13 to 0.22 mm. The apertures are circular, 0.11 mm. in diameter, and are surrounded by distinct, but only slightly raised, peristomes; three apertures occur in the length of each fenestrula, and an extra one may occur opposite the dissepiment; the distance between the centres of successive apertures is from 0.24 to 0.3 mm., and about thirty-eight apertures occur in 10 mm. The fenestrules are oval, from 0.6 to 0.75 mm. in length, and from 0.24 to 0.35 mm. in width, and the dissepiments are from 0.21 to 0.27 mm. in width. On the celluliferous surface each dissepiment shows one or two strong transverse furrows. The reverse surface is not shown. Bifurcation occurs at intervals of more than 5 mm.; increase to three rows of zoocia occurs within one fenestrula before branching.

Remarks: The numerous low, contiguous nodes distinguish this form from any described Permian species. *Fenestrellina inaequalis* (Ulrich), from the Upper Coal Measures of Illinois, is similar in appearance; it is, however, a larger species, with rather more zoocia to a fenestrula, and shows smaller and much more numerous nodes.

Fenestrellina valentis sp. nov.

Plate 1. Fig. 4.

Holotype: Specimen 2793e, University of Western Australia Collection. (Coll. H. W. B. Talbot).

Horizon and locality: Nooncanbah Series; 6½ m. North of Mt. Anderson.

Fenestrellina with three to four zooecia to a fenestrula; very broad branches; rounded carina with small nodes.

There are 10 branches horizontally, and 10 fenestrules vertically, in 10 mm. The branches are very broad, from 0.63 to 0.75 mm. in width, and show a median, rounded, relatively low carina, with rather small, rounded nodes, placed from 0.24 to 0.4 mm. apart. The apertures are circular, 0.13 mm. in diameter, and are placed on the flattened sides of the branches; no peristomes are shown. From three to four apertures occur in the length of one fenestrula and one dissepiment; the distance between the centres of successive apertures is from 0.29 to 0.35 mm., and about 33 apertures occur in 10 mm. The fenestrules are oval, from 0.52 to 0.68 mm. in length, and from 0.36 to 0.44 mm. in width; the width of the dissepiments is from 0.4 to 0.48 mm. A cast of the reverse surface shows that both branches and dissepiments are evenly rounded, and that they are of the same thickness (about 0.4 mm.). On the celluliferous surface the dissepiments show numerous fine transverse striae when they are very slightly weathered.

Remarks: The broad, flattened branches and dissepiments distinguish this form from associated species.

***Fenestrellina columnaris* sp. nov.**

Plate 2, Fig. 3; Text-figure 1 F, G.

Holotype: Specimen 20949, University of Western Australia Collection. (Coll. C. Teichert and H. Coley.)

Horizon and locality: Lower half of the Caleolisporgia Stage of the Wandagee Series; Syncline on Minilya R., $\frac{1}{2}$ mile West of Coolkilya Pool.

Fenestrellina with three zooecia to a fenestrula; carina slight, nodes large and very high.

The colony was probably infundibuliform; the holotype is a large, very much folded expansion. There are 16 branches horizontally, and from 14 to 15 fenestrules vertically, in 10 mm. The branches are straight, from 0.33 to 0.38 mm. in width, and show a slight median carina, which bears a single row of high nodes, placed from 0.33 to 0.4 mm. apart. These nodes are slightly elongated along the carina at their bases, but above this they are rounded in cross section, and terminate bluntly; their height is up to 0.17 mm., and their diameter at the top may be as much as 0.2 mm., though it is generally less. The apertures are circular, 0.13 mm. in diameter, and are placed on the sloping sides of the branches, but do not project into the fenestrules; peristomes are not developed. Three apertures occur in the length of each fenestrula, and one of these may be placed opposite the end of a dissepiment; the distance between the centres of successive apertures is from 0.25 to 0.29 mm., and about thirty-seven apertures occur in 10 mm. Bifurcation of the branches may occur within 5 mm.; increase to three rows of zooecia occurs immediately before branching. The fenestrules are oval, from 0.44 to 0.5 mm. in length, and about 0.25 mm. in width; the width of the dissepiments is from 0.22 to 0.3 mm. On the reverse surface both branches and dissepiments are evenly rounded, although after slight weathering they appear angular; the dissepiments are as thick as the branches—about 0.75 mm.; the outermost layer of the reverse surface is finely granular. Rootlets, which are often forked, and are up to about 8 mm. in length, may be developed from the reverse surface.

Remarks: From *Fenestrellina horologia* (Bretnall) this species is distinguished by its larger size, by having more zoocia to a fenestrules, and by its large nodes. *Fenestrellina pulchradorsalis* (Bassler) is a larger species, and does not show large nodes.

***Fenestrellina lennardi* sp. nov. (Text figure 1A.)**

Holotype: Specimen 20948a, University of Western Australia Collection. (Coll. C. Teichert.)

Horizon and locality: Highest beds of the Nooncanbah Series; South side of Mt. Marnion, Kimberley District.

Fenestrellina with one aperture to a fenestrule; carina slight; nodes small.

The form of the colony is not shown; there are about 31 fenestrules vertically, and about 22 branches horizontally, in 10 mm. The branches are straight and flattened, and show a slight, rounded, rather wavy carina; small nodes are developed, but are not well shown. The branches are relatively very broad, being from 0.24 to 0.32 mm. in width; the zoocial apertures are circular, 0.1 mm. in diameter, and are surrounded by slight peristomes; they are usually very regularly placed, one occurring opposite the end of each dissepiment. The distance between the centres of successive apertures is from 0.29 to 0.38 mm., and about 31 occur in 10 mm. The fenestrules are oval, from 0.17 to 0.25 mm. in length, and generally about 0.21 mm. in width; the width of the dissepiments is about 0.1 mm. The reverse surface is not shown. Bifurcation occurs at relatively distant intervals, and increase to three rows of zoocia occurs just before branching.

Remarks: The small size of this species, and the arrangement of the zoocial apertures, separate it from associated species.

***Fenestrellina cacuminatis* sp. nov. (Text figure 1B.)**

Holotype: Specimen 20944a, University of Western Australia Collection. (Coll. A. Wade.)

Horizon and locality: Nooncanbah Series: Keevie's Well, 8 miles North of Mt. Anderson Homestead.

Fenestrellina with three zoocia to a fenestrule; carina slight; nodes small, sharp, evenly spaced.

The form of the colony is not shown; there are 14 fenestrules vertically, and 22 branches horizontally, in 10 mm. The branches are straight, about 0.25 mm. in width, and the carina is formed principally by the junction of the sloping sides of the branches; the nodes are small and sharp, but not high, and are placed from 0.24 to 0.29 mm. apart. The apertures are circular, 0.08 mm. in diameter, and are placed on the sloping sides of the branches; slight peristomes are developed, and where they are well-preserved the apertures project slightly into the fenestrules. The distance between the centres of successive apertures is from 0.22 to 0.27 mm., and about 42 occur in 10 mm.; there are three apertures to a fenestrule—one of these may be placed opposite the end of a dissepiment. The fenestrules are oval, from 0.52 to 0.63 mm. in length, and from 0.17 to 0.25 mm. in width; the dissepiments are about 0.12 mm. wide. On the obverse surface the dissepiments when slightly worn, show a few transverse grooves. The reverse surface is not shown.

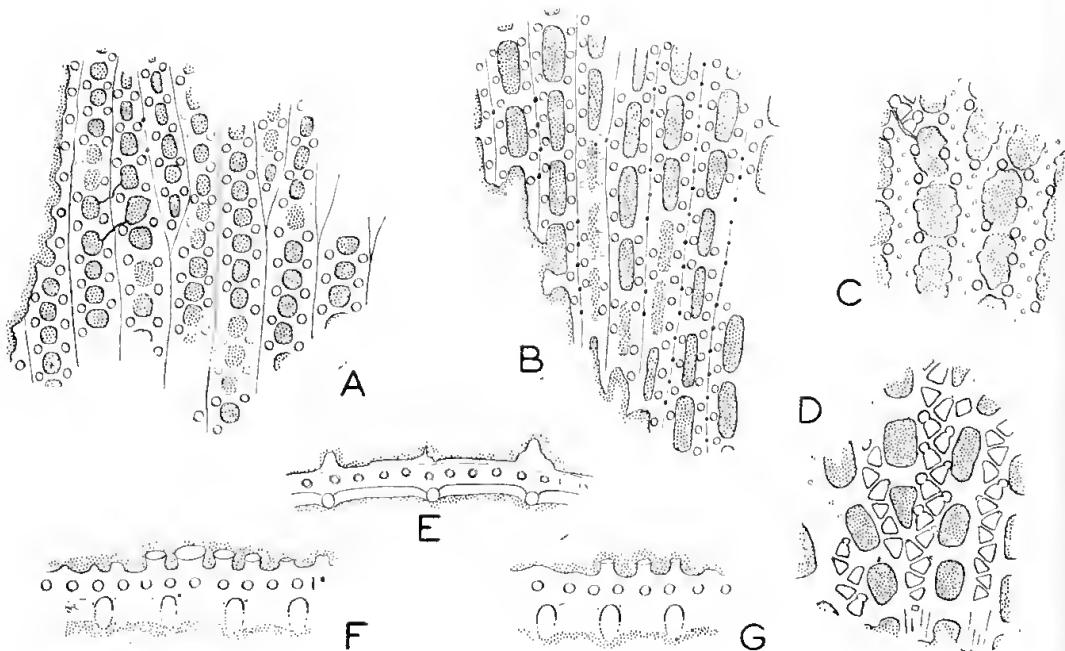
Remarks: This species is distinguished from *Fenestrellina pulchradorsalis* (Bassler) by its narrower branches and dissepiments, and smaller size. *F. affluens* (Bretnall) is a larger species.

Genus **MINILYA** gen. nov.

Fenestrellinae in which the branches show two rows of alternating zooecia, one on each side of a slight median carina; nodes small, in two rows on the carina, placed so that one node is lateral to each zoocial aperture; zooecia sub-triangular; structure of the reverse surface as in *Fenestrellina*.

Range: Upper Pennsylvanian to Permian.

Genotype: *Minilya duplaris* sp. nov.



Text-Figure I.

A. *Fenestrellina lennardi* sp. nov.: Celluliferous surface of the holotype (No. 20948a, Univ. of Western Australia), x 10.

B. *Fenestrellina cacuminatis* sp. nov.: Celluliferous surface of the holotype (No. 20944a, Univ. of Western Australia), x 10.

C. *Minilya duplaris* sp. nov.: Portion of a thin section of a specimen from the Calceolispongia Stage of the Wandagee Series (Specimen in the University of Western Australia Collection), showing the double row of nodes and the arrangement of the zoocellar apertures; the section has cut just above the level of the dissepiments, x 10.

D. *Minilya duplaris* sp. nov.: A thin section of the same specimen, showing the shape of the zooecia, and, on the left hand side, some of the tubercles characteristic of the reverse surface of this species, x 10.

E. *Fenestrellina disjecta* sp. nov.: Lateral view of part of one branch of a topotype (Specimen 2793b, University of Western Australia Collection), x 10.

F, G. *Fenestrellina columnaris* sp. nov.: Lateral views of two branches of the holotype, x 10.

(*Camera lucida* diagrams.)

Species belonging to this late Palaeozoic group have been described from the Upper Pennsylvanian of Texas and Kansas, and from the Permian of India, Timor, Kansas, Texas, Nebraska, and Eastern and Western Australia. A list of the measurements of some of the species

belonging here has been given by Elias (1937, p. 324). The following are amongst the species included in this group:—

Fenestella geminanoda Moore (Upper Pennsylvanian to Lower Permian).
Fenestella bispinulata Moore (Upper Pennsylvanian).
Fenestella binodata Condra (Upper Pennsylvanian).
Fenestella eonradi var. *compactilis* Condra (Upper Pennsylvanian to Lower Permian).
Fenestella kukuensis Bassler (Permian).
Fenestrellina bituberculata Crockford (Permian).
Fenestella perelegans Meek, Waagen and Pichl (not *Fenestella perelegans* Meek), (Permian).
^{*}*Fenestella jabiensis* Waagen and Pichl (Permian).
Minilya duplaris sp. nov. (Permian).
Minilya princeps sp. nov. (Permian).

Minilya duplaris sp. nov.

Plate I, figs. 5, 7; Text-figure 1 C, D.

Fenestella horologia Bretnall, Hosking, 1931, *Jour. Roy. Soc. W.A.*, Vol. XVII, p. 13, pl. IV, fig. 3.

[non] *Fenestella horologia* Bretnall, 1926, *W.A. Geol. Surv. Bull.* 88, p. 15, pl. I, fig. 6.

[ef.] *Fenestella perelegans* Meek, Waagen and Pichl, 1885, *Pal. Indica, Ser. XIII*, Vol. I, p. 777, pl. LXXXVII, figs. 1-3.

[non] *Fenestella perelegans* Meek, 1871, in Heyden's Final Report on Nebraska, p. 153, pl. VII, fig. 3.

Holotype: Specimen 2793d, University of Western Australia Collection. (Coll. H. W. B. Talbot).

Horizon and locality: Nooncanbah Series, 6^{1/2} miles North of Mt. Anderson.

Minilya with two zoocelia to a fenestrula; carina slight; nodes sharp, relatively high, in two rows on the carina; reverse surface tuberculate.

The form of the colony is not shown; there are from 16 to 19 branches horizontally, and from 14 to 17 fenestrules vertically, in 10 mm. The branches are straight, from 0.33 to 0.41 mm. in width, and show a slight median carina, which may be produced upwards in a very thin, zig-zag ridge between the nodes, which are in two rows and are alternating; the nodes, where they are well preserved, are sharp and relatively high, and each node is placed lateral to an aperture; adjacent nodes are from 0.13 to 0.17 mm. apart. The apertures are circinal, about 0.13 mm. in diameter; very thin peristomes are developed, but these are usually broken away. The apertures are placed on the steeply sloping sides of the branches, and project into the fenestrules; the distance between the centres of successive apertures is from 0.27 to 0.35 mm. (average 0.3 mm.), and about 33 oeocn in 10 mm. There are two apertures in the length of one fene-

* In 1915 Frederiks (pp. 47-48) described a new sub-genus of *Fenestella*, *Fenestepora*, with three species, *Fenestepora jabiensis* (Waagen and Pichl), *Fenestepora foraminosa* (Eichwald), and *Fenestepora retiformis* (Schlotheim). The species considered by Frederiks to be identical with *Fenestella jabiensis* Waagen and Pichl is a different species; *Fenestepora* is considered to be a distinct genus, and *Fenestepora jabiensis* Frederiks (not Waagen and Pichl) has been chosen as genotype by Bassler (1935).

Fenestepora Frederiks is distinguished from *Fenestrellina* d'Orbigny by the presence of a row of small cellules (as distinct from nodes) on the carina of each branch.

strule and one dissepiment, and these are generally regularly placed, with one opposite the end of each dissepiment, and one at the centre of each fenestrule, but one specimen shows slight irregularities in the placing of the apertures. The fenestrules are hourglass-shaped or oval, and are from 0.4 to 0.51 mm. in length and from 0.14 to 0.25 mm. in width; the dissepiments are from 0.11 to 0.3 mm. in width, and the length of one fenestrule and one dissepiment is from 0.51 to 0.73 mm. The reverse surface is not shown in specimens from the type locality, but specimens from the highest beds of the Nooncanbah series at Mt. Marmion, and from the Calecolispongia Stage of the Wandijee Series on the Minilya River show that the reverse surface of the branches is ornamented by very numerous, large, irregularly placed tubercles; the inner layers of the reverse surface show five or six fine longitudinal striae. The dissepiments are not quite so thick as the branches. Sections show that both superior and inferior hemisepta are developed; the shape of the zooecia is shown in Text-figure 1 D; they show a greater resemblance to those described by Nikiforova (1933, p. 13) for the *Fenestrellina donaica* group than to those of other forms. The tubercles of the reverse surface show in sections as rounded areas of lighter colour. Bifurcation generally occurs at infrequent intervals, but may occur within 3 mm.; increase to three rows of zooecia occurs immediately before branching.

Remarks: This species is probably the form described by Miss Hosking (1931) from the Woorene River District as *Fenestella horologia* Bretnall, but it differs from *F. horologia* in having a double, instead of a single, row of nodes. It occurs in the Springsure District, Queensland (Consuelo Ck., two miles above Cattle Ck.; Reid, 1930, p. 157, locality 9). *Fenestella conradi* var. *compactilis* Condra, from the Upper Pennsylvanian and Lower Permian of Kansas and Nebraska, is differentiated by having less regularly arranged apertures and smaller nodes, which may not always be placed in two rows, as they are shown in Condra's figures; the measurements and figures given by Condra for this species do not always correspond. *Fenestella bispinulata* Moore, from the Upper Pennsylvanian of Kansas, is a smaller species, and differs in the appearance of the reverse surface. The species recorded as *Fenestella perelegans* Meek from the Middle Productus Limestone of the Salt Ranges by Waagen and Pichl is slightly finer than this species, as was noted by Miss Hosking, and possibly shows a rather higher carina: the reverse surfaces of the specimens examined by Waagen and Pichl were very much weathered; it is possible that these two species are identical. *Fenestrellina perelegans* (Meek), from the Coal Measures of Nebraska, possessed only a single row of nodes on the carina.

Minilya princeps sp. nov.

Plate 1. Fig. 1.

Holotype: Specimen 20945, University of Western Australia Collection. (Coll. A. Wade.)

Horizon and locality: Nooncanbah Series; Keevie's Well, 8 miles north of Mt. Anderson Homestead.

Minilya with three zooecia to a fenestrule; carina almost obsolete; nodes small, in two rows on the carina.

The form of the colony is not shown; there are from 10 to 10.5 fenestrules vertically, and 17 branches horizontally, in 10 mm. The branches

are straight, and are rounded on the celluliferous surface; they are from 0.41 to 0.48 mm. in width. The carina is broadly rounded and is poorly defined, and shows two rows of rather small nodes, which regularly alternate; each node is placed lateral to a zoocial aperture; the distance between adjacent nodes is from 0.13 to 0.21 mm. The apertures are circular, 0.13 mm. in diameter, and are placed on the sloping sides of the branches; they may project very slightly into the fenestrules; the peristomes are very poorly defined. There are usually two apertures in the length of each fenestrule, with an extra one opposite each dissepiment; the distance between the centres of successive apertures is about 0.35 mm., and twenty-eight apertures occur in 10 mm. The fenestrules are oval, from 0.57 to 0.62 mm. in length, and about 0.2 mm. in width; the width of the dissepiments is from 0.32 to 0.36 mm. On the celluliferous surface the dissepiments are rounded, and are covered by a thick, finely granular deposit; they are not depressed very much below the surface of the branches. On the reverse surface the branches and dissepiments are of the same thickness; both are evenly rounded; the outermost layer is finely granular. Bifurcation occurs at infrequent intervals, and increase to three rows of zoocia occurs immediately before branching.

Remarks: This species differs from *Fenestella jabiensis* Waagen and Pichl, from the Middle and Upper Productus Limestone of the Salt Ranges, in having fewer zoocia to a fenestrule, and a less well defined keel, and in having the dissepiments on the celluliferous surface nearly level with the branches; and from *Fenestella binodata* Condra in having fewer fenestrules in 10 mm., and much more widely spaced zoocia. *Minilya duplaris* sp. nov. is a finer form, and shows fewer zoocia to a fenestrule.

Genus **POLYPORA** McCoy.

Polypora McCoy, 1845, Synopsis of the Carboniferous Limestone Fossils of Ireland, p. 207.

Genotype: *Polypora dendroides* McCoy, 1845.

Infundibuliform or flabellate Fenestrellinidae, with the zoocia arranged in three or more rows on the branches, except just after bifurcation, when only two rows may be present; nodes (acanthopores) usually present, but carina not usually developed; dissepiments not celluliferous; internal structure and reverse surface as in Fenestrellina.

Polypora fovea sp. nov.

Plate 3. Figs. 1, 3.

Holotype: Specimen 20947, University of Western Australia Collection (Coll. A. Wade.)

Horizon and locality: Nooncanbah Series; Keevie's Well, 8 miles north of Mt. Anderson Homestead.

Polypora with four to five rows of zoocia, and four to five zoocia to a fenestrule; nodes small, infrequently developed; branches and dissepiments narrow.

There are 8 to 12 branches horizontally, and 6 to 6.5 fenestrules vertically, in 10 mm. The branches are straight and are relatively very narrow, being from about 0.45 mm. in width where there are four, to as much as 0.7 mm. where there are five, rows of zoocia; they usually show four to five rows of zoocia, with three—less often two—for one or two fenestrules after, and five to six just before, branching. The apertures are sub-circular,

0.11 by 0.06 mm. in diameter, and are surrounded by well-developed peristomes; they may be closed by a calcareous plate, frequently showing a small central perforation; the whole of the celluliferous surface shows strong ridges and grooves around and between the apertures. There are five, less often four, apertures to a fenestrule, the distance between the centres of successive apertures being from 0.25 to 0.35 mm.; about thirty-one apertures occur in 10 mm. Small nodes are irregularly developed. The fenestrules are sub-rectangular, from 1.15 to 1.36 mm. in length, and from 0.3 to 0.95 mm. in width; the dissepiments, which expand only slightly at their junction with the branches, are from 0.17 to 0.29 mm. in width. On the celluliferous surface the dissepiments are evenly rounded, and each shows four or five strong transverse ridges and grooves. On the reverse surface both branches and dissepiments are rather sharply rounded; the branches are rather thicker than the dissepiments, and show numerous fine longitudinal striae when they are very slightly worn; a row of fine tubercles may occur across the back of a branch at its junction with a dissepiment, but these are not always developed. The dissepiments show fine transverse ridges and grooves. Bifurcation of the branches occurs at intervals of 5 mm. or more.

Remarks: *Polypora virga* Laseron, which occurs in the Upper Marine Series in New South Wales, is a larger form, with usually three rows of zoocia.

Polypora retificis sp. nov.

Plate 2. Fig. 4.

Holotype: Specimen 20951, University of Western Australia Collection. (Coll. C. Teichert and H. Coley).

Horizon and locality: Calceolispongia Stage of the Wandagee Series: Syncline on Minilya River, half mile West of Cookilya Pool.

Polypora with three rows of zoocia, and four zoocia to a fenestrule; nodes very large, but infrequently developed.

The form of the colony is not shown; there are 9 fenestrules vertically, and 15 to 17 branches horizontally, in 10 mm. The branches are straight or slightly flexuous on the obverse surface, and normally show three rows of zoocial apertures, with four just before, and two for about two fenestrules after, branching; there is a slight carina where only two rows of apertures occur. Large nodes about 0.22 mm. in diameter are irregularly and infrequently developed, generally in the mid-line of the branch. There are four apertures in the length of one fenestrule and one dissepiment, either one or two of these being placed opposite the end of the dissepiment; the distance between the centres of successive apertures is from 0.24 to 0.38 mm., and about thirty-three apertures occur in 10 mm. The apertures are circular, about 0.11 mm. in diameter, and show thin peristomes; over a large part of the surface the apertures have been enlarged, and the peristomes removed, by weathering. The apertures may encroach on the ends of the dissepiments, but extra cells do not normally occur; in one place two branches each showing two rows of zoocia coalesce for a short distance after their separate bifurcations. The fenestrules are oval on the celluliferous surface, and are from 0.67 to 0.8 mm. long, and from 0.33 to 0.5 mm. wide; the width of the dissepiments is from 0.41 to 0.6 mm., and the length of one fenestrule and one dissepiment is from 1.16 to 1.38 mm. On the reverse surface both branches and dissepiments are rounded, and the fenestrules appear round or oval; the dissepiments are generally slightly

thinner than the branches; the outermost layer of the reverse surface is finely granular, but when it is weathered fine concentric striae are shown. On the celluliferous surface the branches are from 0.48 to 0.57 mm. in width where there are three, from 0.3 to 0.38 mm. where there are two, and about 0.85 mm. where there are four, rows of zooecia. Bifurcation may occur within 5 mm.

Remarks: *Polypora woodsi* (Etheridge) is differentiated by its far more numerous, and much smaller, nodes.

Polypora woodsi (Etheridge).

Plate 3, fig. 2.

Protoretepora ampla var. *woodsi* Etheridge, 1892, Geology and Palaeontology of Queensland and New Guinea, p. 222, pl. 8, fig. 12.

Protoretepora ampla Lonsdale, de Koninck, 1878, *Mem. Soc. Roy. des Sciences de Liège, Ser. 2, Tome VII*, p. 42, t. 8, figs. 5 a - e.

[non] *Fenestella ampla* Lonsdale, 1844, in Darwin, Geological Observations on Volcanic Islands, p. 163.

Polypora tumula Lanson, 1918, *Jour. Roy. Soc. N.S.W.*, Vol. LII, p. 191, pl. VII, fig. 3, pl. IX.

Polypora tripliseriata Bassler, 1929, *Palaeontology von Timor*, Lief XVI, XXVIII, Permian Bryozoa of Timor, p. 79, pl. CCXLII (18), figs. 14-16.

Polypora woodsi Etheridge (Crockford), 1941, *Jour. Roy. Soc. N.S.W.*, p. 414, pl. XVIII, fig. 1, pl. XIX, fig. 1.

Specimens of this species occur in the material from three of the localities in the Kimberley District; the characters shown agree with those of the neotype.

Remarks: In New South Wales this species is abundant in the *Fenestella* Shales (Branxton Stage of the Upper Marine Series) in the Hunter River District, and in the Ulladulla Mudstones (probably about the same horizon in the Upper Marine Series) of the South Coast; it is not known from any other horizon in New South Wales. In Tasmania it occurs at Marlborough, and in the Grange Stage near Hobart; it has been recorded by Etheridge from Queensland, and occurs in the Springsure District (Consuelo Ck., two miles above Cattle Ck.; Reid, 1930, p. 157, locality 9). It occurs also in the Callytharra Stage of the Wooramel R. District. *Polypora tripliseriata* occurs in the Bitaoeni Beds at Kampong Apna in Timor.

Polypora multiporifera sp. nov.

Plate 3, fig. 4.

Holotype: F. 38441, Australian Museum Collection (Coll. H. Coley).

Horizon and locality: Caleolisporgia Stage of the Wandagee Series, Syncline on Minilya River, half mile West of Coolkilya Pool.

Polypora with five to six rows of zooecia, and from six to fourteen zooecia to a fenestrule; branches slightly convex; fenestrules long, irregular in length, and rather narrow; nodes small, fairly abundant.

There are from 1.5 to 2.5 fenestrules vertically, and about five branches horizontally, in 10 mm.; the branches are straight, and are rather rounded on the celluliferous surface, so that the lateral rows of apertures may open towards the fenestrules; they are from about 0.7 to 0.9 mm. wide where there are four, from 0.97 to 1.1 mm. where there are five, and about 1.1

mm. where there are six rows of zoocelia; the width increases rather rapidly before branching, which occurs at relatively short intervals. Small nodes were apparently rather abundant, though they are now frequently weathered away; generally not more than two occur adjacent to each zoocelial aperture. The whole of the celluliferous surface is finely tuberculate; the dissepiments show numerous fine transverse striae where they are slightly worn. There are usually five to six rows of zoocelial apertures, with from six to seven before, and from three to four after, branching; the apertures are circular, about 0.16 mm. in diameter; no peristomes are shown; the distance between the centres of successive apertures is from 0.38 to 0.49 mm., and about twenty-two apertures occur in 10 mm. with from six to fourteen opposite each fenestrule. The fenestrules are from 2.1 to 5.6 mm. in length, and from 0.65 to 1.1 mm. in width; the dissepiments, which are not celluliferous, are from 0.46 to 0.6 mm. in width. The reverse surface is not shown. The cells are short and are rhomboidal in shape; they are from 0.32 to 0.38 mm. in length, and are about 0.24 mm. in width at their widest part; the extremities of successive cells in the same row are not in contact. No surface cells are developed.

Remarks: The rather numerous small nodes, the absence of any rounded surface cells, and the short, broad zoocelia separate this species from *Polypora magnafenestrata* Crockford, from the Lower and Upper Marine Series of New South Wales.

Polypora sp. nov. indet.

Plate 2, fig. 5.

Horizon and locality: Nooncanbah Series; scarp two miles East of Christmas Ck. Homestead. (Specimen 20952 a, University of Western Australia Collection; Coll. A. Wade).

Polypora with about eight rows of zoocelia, and with from nine to fifteen apertures to a fenestrula; nodes not developed.

The specimen is a rather weathered cast of the celluliferous surface, and the form of the colony is not well shown, though it was probably infundibuliform, with the celluliferous surface internal. There are from 3 to 4 branches horizontally, and from 1.5 to 2 fenestrules vertically, in 10 mm. The branches bifurcate at relatively very frequent intervals, generally less than the length of one fenestrula apart; they are usually from 1.2 to 1.55 mm. in width, but broaden considerably just before bifurcation. There are normally about seven or eight rows of zoocelial apertures; the branches are thick and very convex, and the lateral rows of apertures open towards the fenestrules. The apertures are circular, about 0.14 mm. in diameter, and the distance between the centres of successive apertures is about 0.49 to 0.6 mm.; the number of zoocelia in the length of one fenestrula and one dissepiment varies with the length of the fenestrules from about 9 to 15. No nodes are shown. The fenestrules are oval, from 3.3 to 6.9 mm. in length, and from 0.86 to 1.41 mm. in width at their widest part; the dissepiments, which expand considerably at their junction with the branches, are from 1.2 to 1.6 mm. in width; they are not celluliferous. The reverse surface is not shown.

Remarks: This species most closely resembles *Polypora gigantea* Waagen and Pichl, from the Middle Productus Limestone of the Salt Range, but is distinguished by its narrower fenestrules and broader dissepiments, and by its much more frequent bifurcations.

ACKNOWLEDGMENTS.

I wish to thank Dr. C. Teichert and Dr. A. Wade for the information which they have given me regarding the localities and horizons of the specimens described, and Dr. I. A. Brown for her help in the preparation of this paper. The majority of the specimens were lent to me by the Department of Geology at the University of Western Australia, but some specimens lent by the Australian Museum have also been used. Three species are recorded from Queensland with the permission of Shell (Qld.) Development Pty., Ltd.

This work has been carried out during the tenure of a Science Research Scholarship at the University of Sydney.

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PLATE I.

Figure 1. *Minilya princeps* sp. nov.: Part of the celluliferous surface of the holotype, showing the two rows of zoocial apertures, and the double row of weathered nodes along the centre of the branch (No. 20945, Univ. of Western Australia), x 10.

Figure 2. *Fenestrellina disjecta* sp. nov.: Part of the celluliferous surface of the holotype (No. 2793a, Univ. of Western Australia), x 10.

Figure 3. *Fenestrellina horologia* Bretuall: Part of the celluliferous surface of a specimen from the Nooneanbal Series at Keevie's Well, 8 miles north of Mt. Anderson Homestead (No. 20942, University of Western Australia). x 10.

Figure 4. *Fenestrellina valentis* sp. nov.: Part of the celluliferous surface of the holotype (No. 2793g, Univ. of Western Australia), $\times 10$.

Figure 5. *Minilya duplaris* sp. nov.: Part of the celluliferous surface of the holotype (No. 2793d, Univ. of Western Australia), $\times 10$.

Figure 6. *Fenestrellina horologia* (Bretnall): Part of figure 3 enlarged to $\times 20$, to show the single row of high nodes, and the apertures, which are stellate where they are best preserved.

Figure 7. *Minilya duplaris* sp. nov.: Part of figure 5 enlarged to $\times 20$, to show the arrangement of the apertures and the double row of nodes.

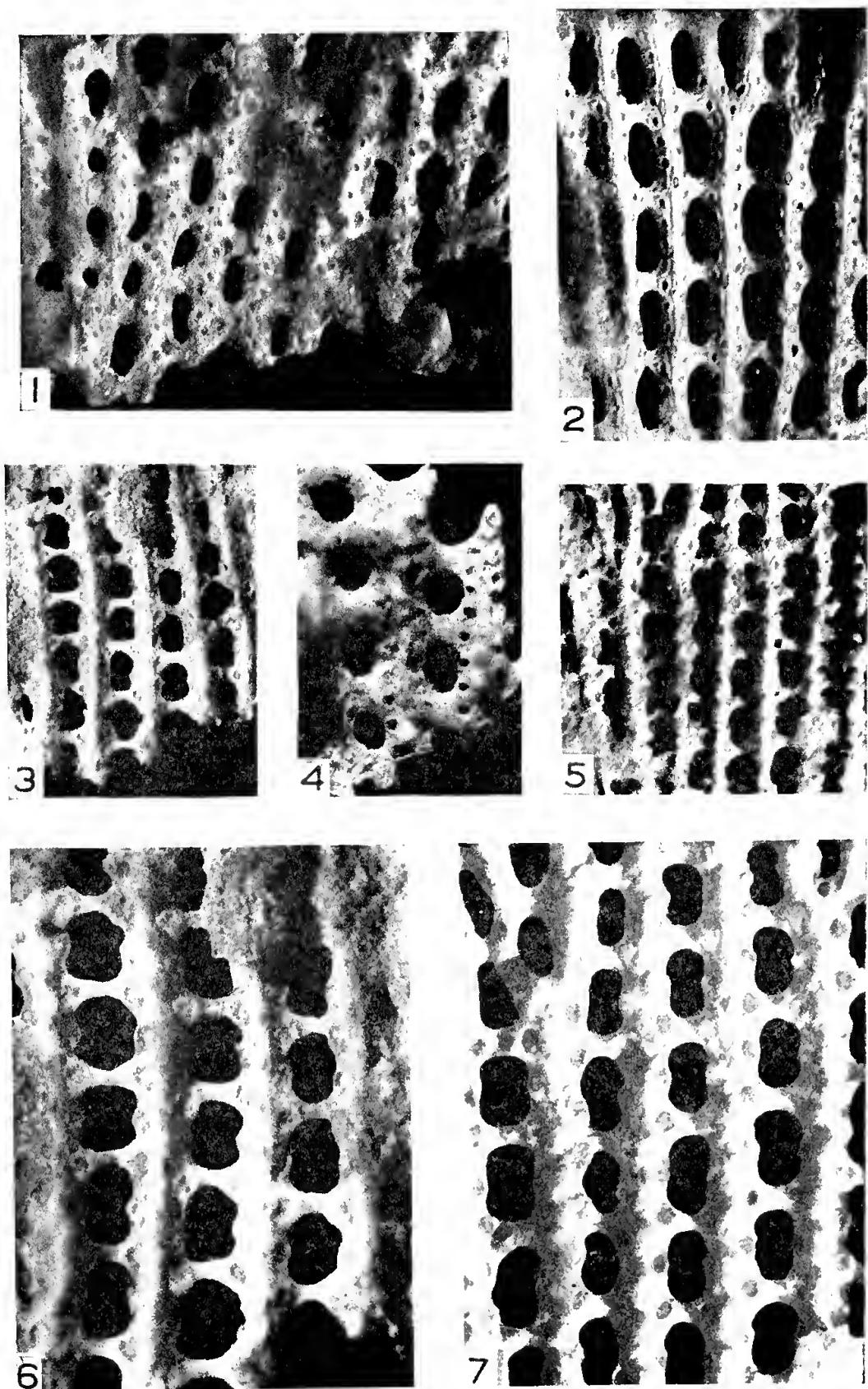


PLATE I.

PLATE II.

Figure 1, 2. *Fenestrellina ruidacarinata* sp. nov.: Part of the celluliferous surface of the holotype (No. 2757a, Univ. of Western Australia), x 10 and x 20.

Figure 3. *Fenestrellina columnaris* sp. nov.: Part of the celluliferous surface of the holotype (No. 20949, Univ. of Western Australia), x 10.

Figure 4. *Polypora reticulata* sp. nov.: Part of the celluliferous surface of the holotype (No. 20951, Univ. of Western Australia), x 10.

Figure 5. *Polypora* sp. nov.: Cast of the celluliferous surface (No. 20952a, University of Western Australia—colony on the lower half of the specimen), natural size.

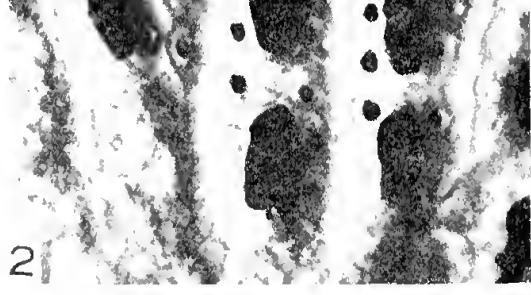
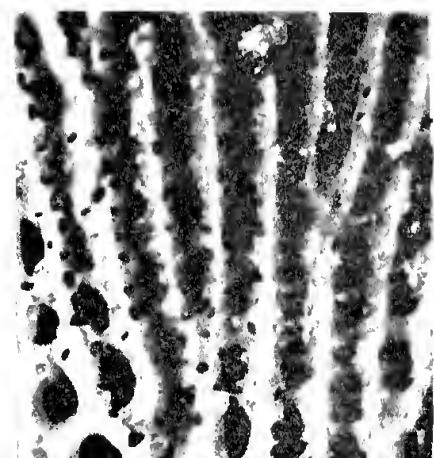
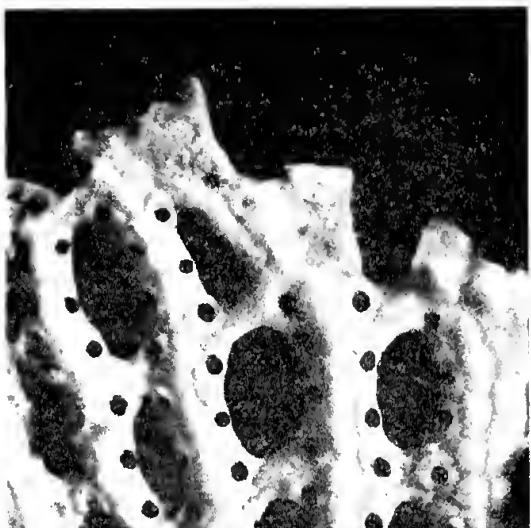


PLATE III.

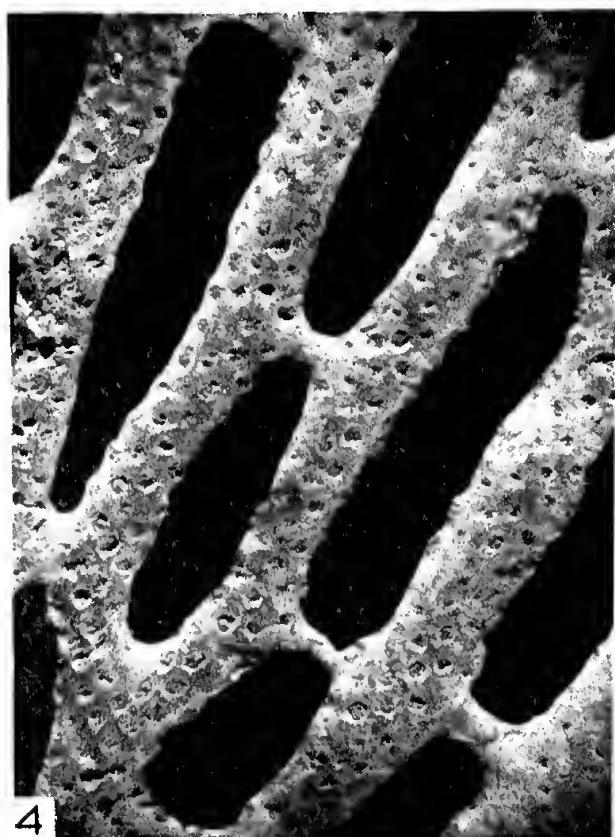
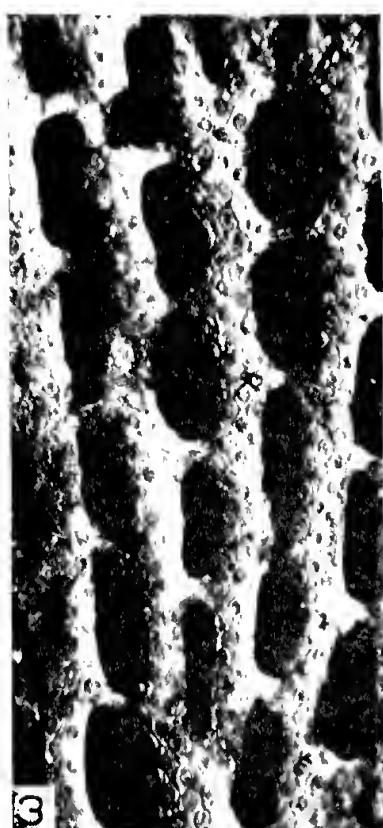
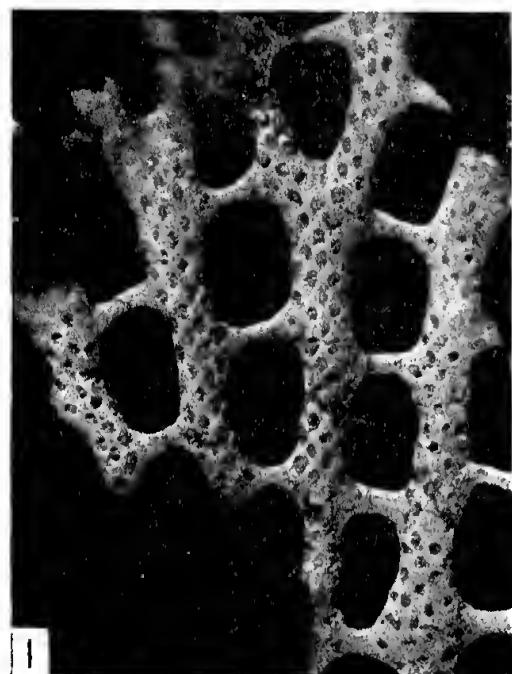
Figure 1. *Polypora forca* sp. nov.: Part of the celluliferous surface of the holotype (No. 20947, Univ. of Western Australia), x 10.

Figure 2. *Polypora woodsi* (Etheridge): Part of the celluliferous surface of a specimen from the Nooneanbah Series at Keevie's Well, 8 miles north of Mt. Anderson Homestead (No. 20943, University of Western Australia), x 10.

Figure 3. *Polypora fovea* sp. nov.: Part of the celluliferous surface of a topotype (No. 20946, University of Western Australia), x 10.

Figure 4. *Polypora multiporifera* sp. nov.: Part of the celluliferous surface of the holotype (No. F. 38441, Australian Museum), x 10.

(Photographs by H. G. Gooch.)



9.—A REVISION OF SOME PREVIOUSLY DESCRIBED
SPECIES OF BRYOZOA FROM THE UPPER
PALAEozoic OF WESTERN AUSTRALIA.

By JOAN M. CROCKFORD, M.Sc.

Read 14th April, 1942: Published 24th March, 1944.

Communicated by PROFESSOR E. DE C. CLARKE.

CONTENTS.

	Page.
Introduction	187
Description of Species:—	
Genus <i>Fenestrellina</i> d'Orbigny.	
<i>Fenestrellina affluensa</i> (Bretnall)	188
<i>Fenestrellina horologia</i> (Bretnall)	189
Genus <i>Lyropora</i> Hall.	
<i>Lyropora erkosoides</i> (Etheridge)	191
Genus <i>Ramipora</i> Toula.	
<i>Ramipora ambrosoides</i> (Bretnall)	193
Acknowledgments	195
Bibliography	195

INTRODUCTION.

Four species of Bryozoa, *Lyropora* (?) *erkosoides* Etheridge, *Fenestella* *affluensa* Bretnall, *Fenestella horologia* Bretnall, and *Aetomocladia ambrosoides* Bretnall, are here revised from the type material in the Western Australian Geological Survey Collection. In the original descriptions of these species the number of the holotype of each species is quoted, but in labelling the specimens the same number was used for all the specimens referred to the species, and in some cases the original labels are now missing; lectotypes are therefore chosen from the syntypes of the species revised, and the specimens have been recatalogued.

DESCRIPTION OF SPECIES.

Phylum BRYOZOA Ehrenberg.

Class GYMNO LAEMATA Allman.

Order CRYPTOSTOMATA Vine.

Family FENESTRELLINIDAE Bassler.

Genus FENESTRELLINA* d'Orbigny.

Fenestrellina d'Orbigny, 1849, *Revue et Magasin de Zoologie*, 2e Sér., Tome I., p. 501.

Homonym:—

Fenestella Lonsdale, 1839, preoccupied for a pelecypod, *Fenestella* Bolten, 1798.

Genotype: *Fenestella crassa* McCoy, 1845.

* An application for suspension of the Rules of Zoological Nomenclature for the generic name *Fenestella* Lonsdale 1839 has been submitted to the International Commission on Zoological Nomenclature by G. E. Condra and M. K. Elias (*Journal of Paleontology*, Vol. 15, no. 4, pp. 565-566).

Infundibuliform or flabellate Fenestrellinidae, with two rows of alternating zoocelia on the branches, except before bifurcation, when the number of rows is increased; rows of zoocelia separated by a median carina, plain or more frequently with a single row of nodes (acanthopores); dissepiments not celluliferous; internal structure and reverse surface as for the family.

Fenestrellina affluensa (Bretnall).

(Plate I., fig. 6.)

Fenestella affluensa Bretnall, 1926, *W.A. Geol. Survey, Bull.* 88, p. 16, pl. I., fig. 8.

Fenestella affluensa Bretnall, Hosking, 1931, *Jour. Roy. Soc. W.A.*, Vol. XVII., p. 12.

Lectotype: Specimen 2/2405E, Western Australian Geological Survey Collection; on specimen figured by Bretnall, 1926, pl. III.

Horizon and locality: Between the top of the Lyons Series and the top of the Byro Series, Gascoyne River District, W.A.

Fenestrellina with three to four zoocelia to a fenestrule; carina slight, rounded; nodes large.

The form of the colony is not shown; the lectotype is about 1.5 cm. long and 1.1 cm. wide. There are from 12 to 14 branches horizontally, and 8 fenestrules vertically, in 10 mm.; the branches are straight, normally from about 0.4 to 0.53 mm. in width, but rather narrower—about 0.35 mm.—where they are slightly weathered; on the celluliferous surface the carina is poorly developed, being represented only by a rounded area free from cells along the centre of each branch, separating the two rows of alternating cell apertures. Nodes are well developed, but are only shown where the surface is best preserved; they are very large and blunt, and are slightly elongated parallel to the length of the branch; their width at the top is up to 0.33 mm., and the distance between the centres of successive nodes is from 0.68 to 0.86 mm. The apertures are normally circular, about 0.14 mm., in diameter, but they may be much enlarged by weathering; they do not generally project into the fenestrules. Thin, raised peristomes are shown where the surface is well-preserved. The distance between the centres of successive apertures is from 0.29 to 0.37 mm., and about thirty occur in 10 mm. The fenestrules are oval—the dissepiments expand considerably at their junction with the branches—and are from 0.85 to 1.2 mm. in length and from 0.3 to 0.5 mm. wide; the width of the dissepiments is from 0.25 to 0.36 mm. Bifurcation occurs at rather distant intervals, and increase to three rows of zoocelia occurs just before branching. The thickness of the branches is about 0.65 mm.

In specimens from the same locality, but not syntypes, the reverse surface shows a number of fine longitudinal striae where it is slightly weathered; the dissepiments are very nearly as thick as the branches, and both are evenly rounded.

Remarks: There are three specimens labelled "17" (the number given by Bretnall as that of the holotype) in the collection; of these the largest and best preserved is here chosen as the lectotype, and the measurements given in the above description were taken on it; there is a second, very small specimen on the same piece of shale, and a third, very much weathered specimen on a piece of limestone from the Callytharra Stage at Fossil Hill, Wyndham River. Both of these show fenestrules slightly longer than the average shown

by the lectotype, though they fall within the range of variation of it ; they are weathered so that the nodes are not visible, but appear to be eonspecific with the lectotype.

Fenestrellina affluensu is distinguished from associated species by its thick branches, and large, well spaced nodes.

Fenestrellina horologia (Bretnall).

(Plate I., fig. J ; Plate II., fig. A.)

Fenestella horologia Bretnall, 1926, *W.A. Geol. Survey, Bull.* 88, p. 15, pl. I., fig. 6.

[non] *Fenestella horologia* Bretnall, Hosking, 1931, *Jour. Roy. Soc. W.A.*, Vol. XVII., p. 13, pl. IV., fig. 3.

Fenestrellina horologia (Bretnall), Crockford, 1944, *Jour. Roy. Soc. W.A.*, Vol. XXVIII., p. 167, pl. I., figs. 3, 6.

Fenestella parviuscula Bassler, 1929, *Paläontologie von Timor*, Lief. XVI., XXVIII., p. 76, pl. 17 (CCXLI.), figs. 8-13.

Fenestella parviuscula Bassler, Martin, 1931, *De Palaeontologie en Stratigraphie van Nederlandsch Oost-Indie*, Bryozoa, p. 391.

Fenestella parviuscula Bassler, Fritz, 1932, *Roy. Soc. Canada, Transactions, Third Series*, Vol. XXVI., Seet. IV., p. 99.

Fenestrellina parviuscula (Bassler), Elias, 1937, *Jour. Paleontology*. Vol. 11, No. 4, p. 314.

Neotype (? Lectotype) : Specimen 2/2405C, Western Australian Geological Survey Collection ; on specimen figured by Bretnall, 1926, pl. III.

Horizon and locality : Between the top of the Lyons Series and the top of the Byro Series, Gascoyne River District, W.A.

Fenestrellina with two zoocelia to a fenestrule ; carina low ; nodes sharp, relatively high, about two to a fenestrule ; fenestrules hour-glass shaped.

The form of the colony is not shown ; there are about 18 branches horizontally, and from 16 to 18 fenestrules vertically, in 10 mm. The branches are straight, from 0.31 to 0.37 mm. in width, and show two rows of regularly alternating zoocial apertures, separated by a slight median carina. Bifurcation occurs at rather distant intervals, and increase to three rows of zoocelia occurs just before branching. The apertures are circular, from 0.08 to 0.1 mm. in diameter, and are placed on the slightly sloping sides of the branches ; the peristomes are not well shown. The apertures are generally very regularly placed, with one opposite the centre of each fenestrule and one at the end of each dissepiment ; the former project into the fenestrules—though the apertures open upwards and not into the fenestrules—and give them their characteristic hour-glass shape. The distance between the centres of successive apertures is from 0.24 to 0.3 mm., and about thirty-seven occur in 10 mm. The nodes are small and sharp, and are placed in a single row on the carina ; they are from 0.24 to 0.3 mm. apart. The fenestrules are from 0.32 to 0.51 mm. in length, and from 0.22 to 0.33 mm.—generally about 0.25 mm.—in width ; the dissepiments are from 0.11 to 0.17 mm. in width. The reverse surface is not shown.

Remarks: *Fenestrellina horologia* was described by Bretnall from material from the Gascoyne River District; the holotype was given as "Geological Survey of Western Australia (specimen 16)." Miss Hosking (1931, p. 13) stated that "the holotype of *F. horologia* (specimen 16 on 10930) is not to be found in the Geological Survey Collection" but (footnote) "A crumpled fragment of a *Fenestella* zoarium is labelled Holotype, but the distinguishing number and the greater part of the zoarium have been broken off." Specimens which she identified as *Fenestella horologia* from the Wooramel River District showed a double row of nodes on the carina; she states that the specimen in the Geological Survey Collection was much the same as these, but was "too crumpled for accurate comparison," and does not say whether a single or a double row of nodes was shown.

There is at present no specimen in this collection labelled "16," and no specimen labelled "Holotype." The labels of many of the specimens have been wholly or partially destroyed, and there are two conspecific fragments of *Fenestrellina*, whose labels have been almost entirely removed, on a specimen of calcareous shale from the Gascoyne River District, figured by Bretnall on Plate III. (this specimen shows several more labels now than at the time it was photographed). Both of these show a slight carina between the two rows of apertures, and over the best preserved parts of the zoaria this carina shows a single row of small, high nodes; both show very well the hour-glass shape of the fenestrules described by Bretnall; it seems probable that these were the specimens used for the original description, and one of them is here chosen as the neotype (? lectotype). A single specimen of a second species showing only two zoaria to each fenestrule is present on the same piece of shale; this specimen shows, very indistinctly, two rows of small nodes on the carina, and is probably the species identified as *Fenestella horologia* from the Wooramel River, described in a separate paper as *Minilya duplaris* gen. et sp. nov. (Crockford, 1944, p. 173); this, the only specimen of this species present in the collection, is very poorly preserved; it does not show any projection of the zoarial apertures into the fenestrules, and the hour-glass shape of the fenestrules is not shown at all in this specimen, though it is shown in specimens from other localities; it is not possible that Bretnall's description could refer to this specimen.

Fenestrellina horologia appears to be the same as *Fenestrellina parviuscula* (Bassler), from the Bitaoeni and Basleo Beds of Timor; in the original description of *F. parviuscula* the width of the branches is given as "about 0.2 mm.", but the branches of the specimens figured appear to be about 0.3 mm. wide, as in the specimens from Western Australia. Elias (1937) has dealt with the relationships of this and similar species. *F. parviuscula* has been recorded from the Permian of Vancouver Island. The fenestrate part of *Lyropora erkosioides* (Etheridge) is very similar in size, but is differentiated by its more widely spaced nodes. *Fenestrellina pectinis* (Moore), which has been recorded by Chapman from the Callytharra Stage at Callytharra Springs, is similar in appearance, but is a smaller species with more closely spaced nodes.

Genus LYROPORA Hall.

Lyropora Hall, 1857, *Proc. Amer. Assoc. Adv. Sci.*, Vol. X., p. 179.

Lyropora Hall, 1890, *Geol. Surv. Illinois*, VIII., pt. II., Sect. IV., pp. 396, 580.

Lyropora Hall, Nickles, and Bassler, 1900, *U.S. Geol. Surv., Bull.* 173, pp. 39, 309.

Lyropora Hall, McNair, 1937, *Michigan University Museum of Paleontology Contributions*, Vol. V., No. 9, p. 114.

Genotype (selected by Ulrich, 1890) : *Lyropora subquadrans* (Hall), 1857 (*L. lyra* (Hall), 1857).

Synonyms :—

Dictyoretmon Whitfield, 1904.

Lyroporella Simpson, 1895.

Lyroporina Simpson, 1897.

Zoarium fenestratae ; colony *flabelliform*, with the sides near the base strongly thickened to form the lateral supports ; branches with two or more rows of zoocelia, dissepiments without zoocelia ; reverse surface and internal structure as in *Fenestrina*.

***Lyropora erkosoides* (Etheridge).**

(Plate I., fig. 2 ; plate II., fig. B.)

Lyropora (?) *erkosoides* Etheridge, in Bretnall, 1926, *W.A. Geol. Survey, Bull.* 88, p. 11, pl. II., figs. 1, 4.

Lectotype : Specimen 2/2404, Western Australian Geological Survey Collection ; figured by Bretnall, 1926, pl. II., fig. 1.

Horizon and locality : Callytharra Stage (?), Well A 20, Daurie Creek, Gascoyne River District, Western Australia.

Lyropora with two rows of zoocelia, and two zoocelia to a fenestrula ; carina slight : nodes sharp, high, evenly spaced.

The zoarium is flabellate ; the base is small and pedunculate, and the sides of the colony above the base are strongly thickened, and form the lateral supports characteristic of the genus. These lateral supports diverge at an angle of about 70° , and the zoarium is celluliferous on the convex surface ; the holotype reaches a height of 4 cm. above the base, and a width, at the top, of about 4 cm. There are about 22 branches horizontally, and 18 fenestrules vertically, in 10 mm. The branches are straight, and are usually from 0.22 to 0.29 mm. in width, but they become much broader towards the supports, and before bifurcation. There are two rows of zoocelial apertures, separated by a very slight median carina on which there is a single row of high nodes, rather elongated along the carina at their bases. The nodes are placed from 0.3 to 0.37 mm. apart. The apertures are circular, about 0.09 mm. in diameter ; slight peristomes are shown—these are best developed on the side towards the fenestrules. There are two apertures to a fenestrula, and over part of the specimen these are arranged so that one is opposite the end of each dissepiment, and one at the centre of each fenestrula, giving the fenestrules an hour-glass shape ; over most of the specimen, however, the arrangement is not regular, and the fenestrules are oval in shape. The distance between the centres of successive apertures is from 0.24 to 0.32 mm., and about thirty-seven occur in 10 mm. The fenestrules are from 0.35 to 0.46 mm. in length, and from 0.17 to 0.29 mm.—generally about 0.2 mm.—in width ; the width of the dissepiments is from 0.13 to 0.21 mm. On the reverse surface both branches and dissepiments are evenly rounded, and they are of about the same thickness—their thickness varies, however, with the distance from the lateral supports. The outer layer of the reverse surface is finely granular ; within this a few fine longitudinal striae are shown. Bifurcation occurs at very distant intervals, and increase to three rows of zoocelia occurs just before branching.

Remarks: There are two specimens labelled "13" (the number given by Bretnall for the holotype of this species) in the material described by Bretnall. The above description is of the figured specimen, here chosen as lectotype. A second specimen, from the Callytharra Stage at Fossil Hill, Wyndham River, does not appear to belong to the same species as the lectotype, from which it differs in the shape of the lateral supports; only a very small portion of the fenestrate part of the zoarium is preserved, along the sides of the lateral supports, and this is decidedly finer than the fenestrate part of the lectotype.

Etheridge referred this species tentatively to the genus *Lyropora* Hall, but, as the celluliferous surface of the specimen was not exposed, considered it possible that the species might belong to one of the genera proposed by Simpson for forms differing from the type of *Lyropora* in the number of rows of zooecia normally present on the branches. The type of *Lyropora*, *Lyropora subquadrans* (Hall) (*L. lyra* (Hall)), selected by Ulrich in 1890, shows from four to five rows of zooecia on the branches; *Lyroporidra* Simpson, 1897, is a synonym of *Lyropora*, since it possesses the same genotype. *Lyroporella* Simpson, 1895, was proposed for forms with two rows of zooecia, the genotype being *Lyropora quincuncialis* (Hall); Nickles and Bassler (1900, p. 310), who considered that the only character of generic importance is the development of lateral supports, and McNair (1937, p. 114) consider *Lyroporella* a synonym of *Lyropora*.

Family **SULCORETEPORIDAE** Bassler,
Genus **RAMIPORA** Toula.

Ramipora Toula, 1875. *Neues Jahrbuch für Mineralogie*, 1875, p. 230, pl. X., figs. 1, 1a.

Ramipora Toula, Shulga-Nesterenko, 1933, *United Geological and Prospecting Service of the U.S.S.R.*, Trudi, Fasc. 259, pp. 32, 54.

Genotype: *Ramipora hochstetteri* Toula, 1875.

Synonym:—

Actomoeladia Bretnall, 1926.

Genotype: *Actomoeladia ambrosoides* Bretnall, 1926.

Zoarium pinnate, with the lateral branches joined by a third set of branches, which may themselves join to form a further set of branches; branches bifoliate, dividing in a plane at right angles to the mesial lamina; mesial lamina running from the centre of the obverse (poriferous) surface to the centre of the reverse (non-poriferous) surface, and projecting slightly above these surfaces so that both are carinate; zooecia sub-tubular, without hemisepta, arranged in more or less regular rows on each side of the carina of the poriferous surface, but not separated internally by vertical plates; lunaria absent or poorly developed; diaphragms extremely rare; acanthopores and mesopores absent; vesicular tissue well-developed internally, interapertural spaces solid at the surface.

Ramipora differs from *Goniocladia* Etheridge in the form of the colony, which is reticulate in *Goniocladia*. *Sulcoretepora* d'Orbigny (*Cystodictya* Ulrich) differs in its mode of branching (in the plane of the mesial lamina instead of at right angles to it), and in the form of the zoarium, and internally in the presence of vertical double plates between the rows of cells.

Bretnall (1926, p. 31) described *Aetomocladia* as a new genus "related to *Pinnatopora* Vine," the genotype being *Aetomocladia ambrosoides* Bretnall, from the Gascoyne River District, W.A., and Fossil Hill, Wyndham River, W.A. Bretnall did not study the internal structure of the genotype, and it has therefore been considered a member of the Acanthocladidae. The internal structure, as is shown under the description of the species given below, is the same as that described by Bassler and Moore for species of *Goniocladia*, and by Shulga-Nesterenko for *Goniocladia* and *Ramipora*, and indicates that *Aetomocladia* is a member of the Sulcoreteporidae allied to these genera; the form of the colony separates *Aetomocladia* from *Goniocladia*, and indicates identity with *Ramipora* (sens. str.).

Ramipora ambrosoides (Bretnall).

(Plate I., figs. 3-5; plate, II., figs. C-F.)

Aetomocladia ambrosoides Bretnall, 1926, *W.A. Geol. Survey, Bull.* 88, p. 21, pl. I., fig. 4.

Aetomocladia ambrosoides Bretnall, Hosking, 1931, *Jour. Roy. Soc. W.A.*, Vol. XVII., p. 12, pl. IV., figs. 5-6.

Aetomocladia ambrosoides Bretnall, Chapman, in Raggatt, *Jour. Roy. Soc. N.S.W.*, Vol. LXX., pp. 106, 128, 148.

Aetomocladia ambrosoides Bretnall, Raggatt and Fletcher, 1937, *Australian Museum Records*, Vol. XX., No. 2, p. 173.

Acanthocladia acuticostata Bassler, 1929, *Paläontologie von Timor*, Lief. XVI., XXVIII., p. 85, pl. 20 (CCXLIV.), fig. 13.

Lectotype: Specimen 2/2405B, Western Australian Geological Survey Collection; on specimen figured by Bretnall, 1926, pl. III.

Horizon and locality: Between the top of the Lyons Series and the top of the Byro Series, Gascoyne River District, W.A.

Fine Ramipora, with from three to five rows of zoocial apertures on each side of the mesial lamina.

Since the lectotype does not show the form of the colony very well, paratypes from the same locality, and from the Callytharra Stage at Fossil Hill, Wyndham River, and a number of specimens from the type locality of the Callytharra Stage in the Wooramel River District, and from the Nooneanbal Series in the Kimberley District have been used for this description; the measurements given, however, were taken only on the lectotype and other specimens on the same piece of shale.

The base of the zoarium is not shown on any of the specimens; the zoarium is pinnate; the branches are bifoliate, and division of the branches takes place in a plane at right angles to the mesial lamina. Lateral (secondary) branches are given off from the main stem, and themselves give off tertiary branches which usually pass straight from one secondary branch to another, but which rarely pass outwards obliquely and join to form a further set of branches. Subsidiary branches appear generally to originate at the same level on opposite sides of a branch, but actually one is nearly always given off very slightly before the other, as is shown by the junction of the mesial laminae of the lateral branches with that of the original branch; very rarely the lateral branches on opposite sides are more widely separated. The distance between the origins of two successive pairs of lateral branches is from

2.5 to 5.5 mm. in these specimens, and the angle at which the lateral branches are given off is from 50° to 77°—in specimens from the Nooncanbah Series this angle is up to 90°. The main stems are usually slightly broader and thicker than the lateral branches, their width being from 1.1 to 1.5 mm., and their thickness about 1.5 mm. ; the width of the secondary branches is from 0.8 to 1.4 mm., and the tertiary branches are slightly narrower.

The branches are bifoliate, with a mesial lamina which runs from the centre of the reverse to the centre of the poriferous surface, and forms a slight ridge along the centre of each surface, so that both are carinate ; the poriferous surface, however, is sharply convex, with the sides sloping steeply outwards, while the reverse surface is rather rounded. On each side of the carina on the poriferous surface there are three or four, less often five, rows of zooecial apertures ; the arrangement of the apertures, however, is not always regular. The apertures are raised above the surface by the development of high peristomes, particularly on the lower side of the aperture ; from sections it appears that no lunaria are developed ; the peristomes are very quickly removed by weathering. When the apertures are arranged in definite rows the amount of alternation between the apertures of adjacent rows is very variable, and often very slight. The apertures are circular, or pyriform where they are weathered, and are from 0.14 to 0.18 mm. in diameter ; they are rather irregularly spaced on all the branches, and the distance between the centres of successive apertures in the same row is from 0.38 to 0.76 mm. (average 0.56 mm.), and about eighteen apertures occur in 10 mm. No acanthopores are developed ; the surface between the apertures is solid. The reverse (non-poriferous) surface is finely granular.

Internally the zooecia are sub-tubular, and the length of individual zooecia is about 1 mm. Diaphragms appear to have been very rarely developed near the proximal ends of the zooecia. The median tubules of the mesial lamina are well-shown, and vesicular tissue is well-developed, particularly near the reverse surface, and at the origin of subsidiary branches.

Remarks : In the original description of the species the "genotype" is given as "specimen 12," but there are seven specimens labelled "12" in the collection ; these belong to three species, but one specimen, belonging to the species to which the original description most closely applies, is labelled "Genotype," and is here chosen as the lectotype of the species.

Of described species of *Ramipora*, the genotype, *R. hochstetteri* Toula, and a specimen recorded by Reed (1925, p. 107, pl. X., figs. 9, 9a), as *R. cf. hochstetteri* from India, most closely resemble this species ; they differ, however, in their broader branches and larger measurements. *Ramipora uralica* Stucken-berg, from the Upper Carboniferous of the Urals, appears to have had lateral branches placed about the same distance apart, but the branches are much broader.

The type specimen of *Acanthocladia acuticostata* Bassler, from the Basleo beds of Timor, appears to be a specimen of this species.

A specimen described as *Ramipora* sp. by Etheridge (1907, p. 14) from the Port Keats Bore appears to have differed from this species in the form of the zoarium and in the much closer spacing of its lateral branches.

ACKNOWLEDGMENTS.

I wish to thank the Government Geologist of Western Australia for the loan of specimens from the Western Australian Geological Survey Collection and Miss Crespin for specimens from the Commonwealth Palaeontological Collection ; and Dr. I. A. Brown for the help which she has given me with the preparation of this paper. This work has been carried out during the tenure of a Science Research Scholarship at the University of Sydney.

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PLATE I.

Figure 1. *Fenestrellina horologia* (Bretnall) : Celluliferous surface of the neotype (? lectotype), x 10.

Figure 2. *Lyropora erkosoides* (Etheridge) : Lectotype, natural size.

Figure 3. *Ramipora ambrosoides* (Bretnall) : Reverse surface (Specimen 118, Commonwealth Palaeontological Collection) from the Callytharra Stage, west of Callytharra Springs, Wooramel River), x 5.

Figure 4. *Ramipora ambrosoides* (Bretnall) : Celluliferous surface of the lectotype, x 5.

Figure 5. *Ramipora ambrosoides* (Bretnall) : Celluliferous surface (Specimen 2793 e, University of Western Australia Collection, from the Nooncanbal Series 6½ miles north of Mt. Anderson, West Kimberley District), x 5.

Figure 6. *Fenestrellina affluens* (Bretnall) : Celluliferous surface of the lectotype, x 10.

(Photographs by H. G. Gooch.)

A REVISION OF SOME PREVIOUSLY DESCRIBED SPECIES OF BRYOZOA 197
FROM THE UPPER PALAEZOIC OF WESTERN AUSTRALIA.

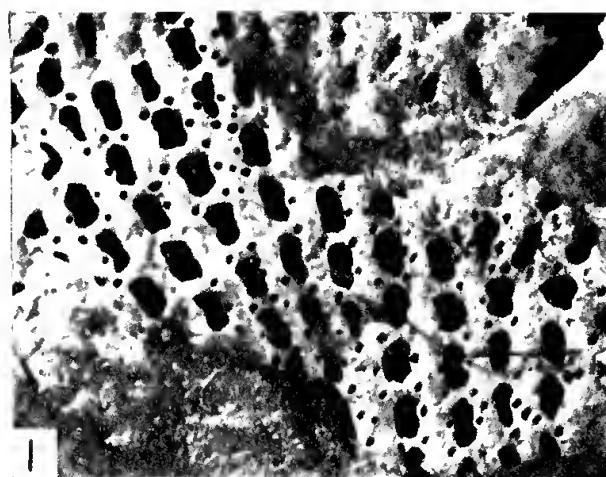


PLATE II.

Figure A. *Fenestrellina horologia* (Bretnall): Celluliferous surface of a topotype, x 20.

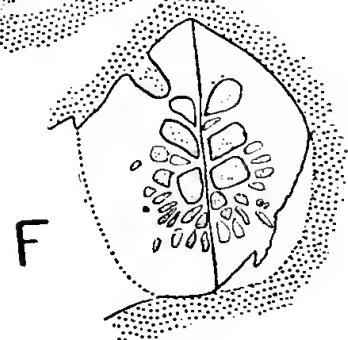
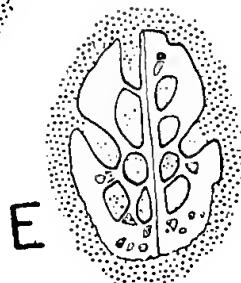
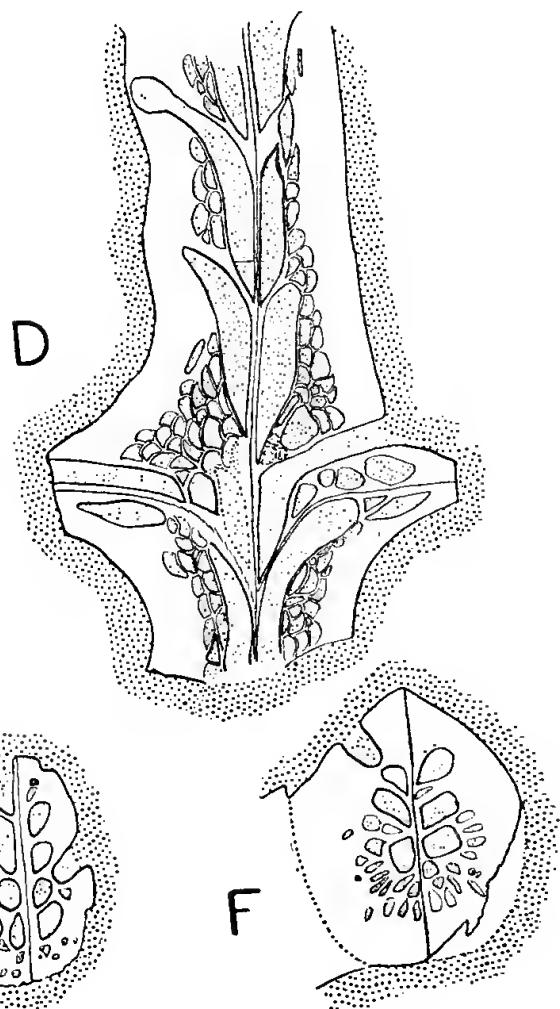
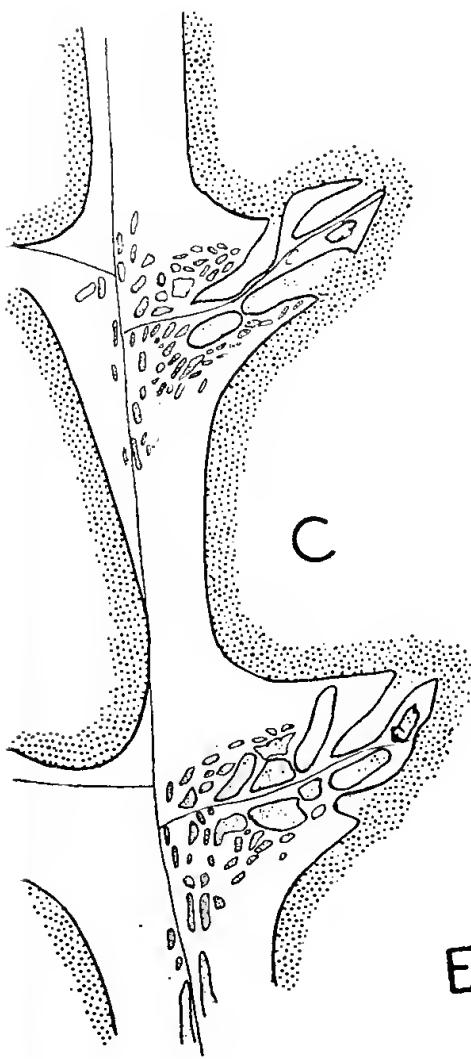
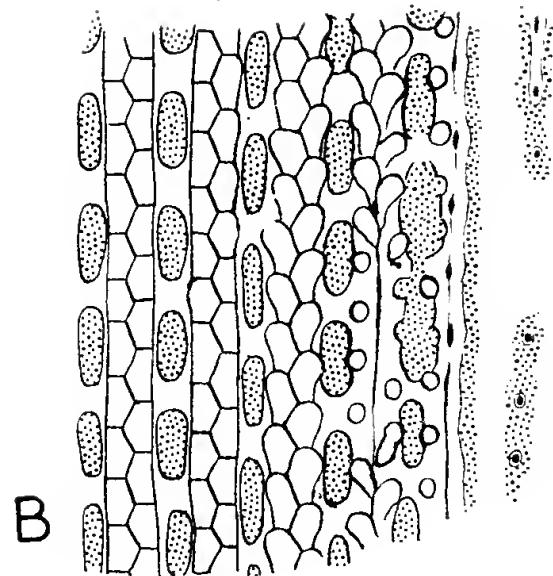
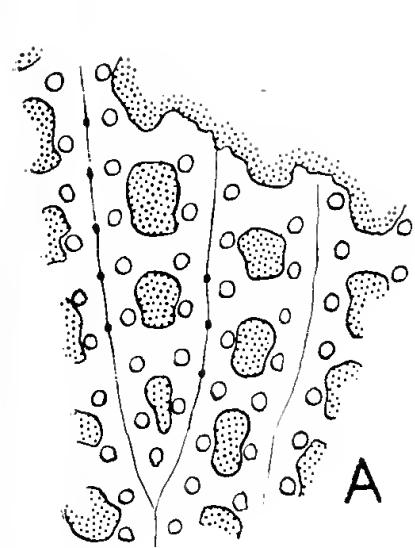
Figure B. *Lyropora ekosoides* (Etheridge): A thin section of the part of the lectotype, x 20. (Slide 6277, Western Australian Geological Survey Collection.)

Figure C. *Ramipora ambrosoides* (Bretnall): Longitudinal section, cut loose to the reverse surface (Slide 2793g, University of Western Australia Collection, from a specimen from the Nooneanbah Series 6½ miles north of Mt. Anderson, West Kimberley District), x 20.

Figure D. *Ramipora ambrosoides* (Bretnall): Longitudinal section of a topotype, cut rather closer to the obverse surface than C. (Slide 6278, Western Australian Geological Survey Collection), x 20.

Figure E, F. *Ramipora ambrosoides* (Bretnall): Vertical sections (Slides 2793 e, f, University of Western Australia Collection, from specimens from the Nooneanbah Series 6½ miles north of Mt. Anderson, West Kimberley District), x 20.

(*Camera lucida* diagrams.)





10.—FOSSIL PLANTS FROM GINGIN, W.A.

By A. B. WALKOM, D.Sc.

The Australian Museum, Sydney.*

(Plates I. II.)

Read 14th April, 1942; published 20th March, 1944.

Abstract.

Fossil plants described from Gingin indicate a Jurassic Age for beds of clayey sandstone underlying the Cretaceous greensands. The collection includes specimens of leaves and sporaangia referred to *Isoetites*, the first record of this genus for Australia.

The collection of fossil plants here described was forwarded to me by Professor E. de C. Clarke in 1937. It is regretted that circumstances have so long delayed the completion of my investigations.

The specimens were obtained from brownish, fine-grained, clayey sandstones underlying the Cretaceous greensands at Gingin, W.A., and the list of species lends support to Professor Clarke's statement, in a letter, that he had "fairly good evidence that the chalk and greensand lie on an eroded surface of the plant beds."

The species identified are:—

Isoetites elegans, sp. nov.

Cladophlebis australis (Morris).

Thinnfeldia talbragarensis Walkom.

Taeniopteris spatulata McClelland.

Ptilophyllum pecten (Phillips).

Elatocladus plana (Feistmantel):

They suggest a Jurassic age for the beds in which they occur, and show closest similarities with the Jurassic flora of the Talbragar Beds in New South Wales.

Perhaps the most interesting feature is the presence of numerous specimens referred to *Isoetites*. Fossil representatives of this group are few in number, and none appear to have been described from rocks of Jurassic age, so the species *I. elegans* may be the earliest species yet known, as well as being the first fossil species known from Australia. The genus *Isoetes* has a wide range at the present day but only six species appear to be recorded from Australia (three from Tasmania, and one each from Queensland, South Australia, and Western Australia).

Professor Clarke has suggested that these plant-bearing beds at Gingin may be the continuation of plant beds at Bullsbrook, some 30 miles north of Perth. In 1931 I examined for him a collection of fragmentary plant remains from the Bullsbrook beds and determined the following species:—*Cladophlebis australis*, ? *Phyllopteris* sp., *Thinnfeldia* sp., *Taeniopteris elongata*, *Nilssonia* sp., and *Elatocladus* cf. *plana*. This small collection was not very satisfactory for determination of the age of the beds and at the time I suggested that possibly a Lower Cretaceous age was indicated. As a whole the Bullsbrook collection does not show close affinities with that from Gingin, and may represent a somewhat higher horizon.

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LYCOPODIALES.

Isoetites elegans, sp. nov.

(Plate I.)

Leaves numerous, long (up to 12 cm. or more), straight or slightly curved, about 3-4 mm. wide at base, tapering to apex, with very fine parallel striations. Sporangia usually 1.5-2 cm. long, by 7-8 mm. Megaspores spherical, about 0.5 mm. in diameter, smooth, with equatorial ridge, and tri-radiate marking on one hemisphere, 40-55 megaspores in a sporangium.

In the specimen figured (Plate I., fig. 1) there are some 36 leaves visible; in addition the bases of a number of other leaves can be observed on the vertical edge of the specimen, so the total number of leaves is greater than 36. The leaves are all simple and there is no indication of dividing as occurs in *Baiera* and allied genera. The tapering of the leaf is very gradual—from 3-4 mm. wide at base to 1 mm. wide at a distance of 12 cm. from the base.

The sporangia vary little in shape, but they may be divided into two distinct groups—one in which the individual megaspores are clearly visible, the other in which little or no structure can be observed (see Plate I., fig. 2). There is some indication in a few of the latter type that the sporangia contain megaspores, outlines of which can be observed. It may be, however, that the majority of these sporangia which show no structure now were the microsporangia and that no details of the microspores are preserved in the specimens available.

The megaspores (Plate I., figs 4, 5), with their equatorial ridge and the tri-radiate marking on the upper half, are of the type characteristic of *Isoetes* and, from the association of the sporangia with the specimen in which the leaves are so similar to those of species of *Isoetes*, it is reasonable to conclude that sporangia and leaves belonged to the one species and to refer them to the genus *Isoetites*. There is indeed evidence that the sporangia occupied the position usual in *Isoetes*, several specimens, of which one is figured (Plate I., fig. 3), showing a sporangium resting on the wide basal portion of a leaf.

Some specimens, such as that figured on Plate I., fig. 2, show a number of sporangia (megasporangia and ? microsporangia) arranged more or less parallel to one another. Some of those on the figured specimen have some indication that they rest on portions of leaves.

In size and shape these fossil sporangia are well within the range of those of recent species of *Isoetes*, as also are the megaspores. The range of size of megaspores in recent species is from 250 to 900 μ . Such species as *Isoetes Engelmanni* and *I. Boryana* would bear comparison with our fossils in this respect (see Pfeiffer, 1922).

There are few recorded fossils that can with certainty be referred to *Isoetites*, so that comparison of the Western Australian specimens with known species is restricted. The leaves are very different from those of *I. serratus* and *I. horridus* from Cretaceous rocks in Wyoming, U.S.A. (Brown, 1939, p. 268) and no details of the megaspores are known in these two species.

The fossils described as *Isoetites Choffati* Saporta from the Lower Cretaceous of Portugal are not comparable with our specimens, since they consist of small tuberous bodies compared with the stem of *Isoetes*, and impressions identified as the basal portions of sporophylls bearing sporangia (*fide* Seward, 1910, p. 67—a copy of Saporta's original description does not appear to be available in Australia).

Type specimens in collection of Geology Department, University of Western Australia: Nos. 16687 (leaves) and 16683 (sporangia). Counterparts of portions of the types are in the collection of the Australian Museum (Nos. F 39818, F 39816).

FILICALES.

Cladophlebis australis (Morris).

There are one or two specimens referable to *Cladophlebis australis*. They are not well preserved and apparently the species is not at all abundant.

Thinnfeldia talbragarensis Walkom.

(Plate II., fig. 8.)

Several specimens agree well with *Thinnfeldia talbragarensis* from Jurassic rocks at Talbragar, N.S.W. (Walkom, 1921, p. 9).

The frond is bipinnate and of the type common in Australian *Thinnfeldias* but there is no indication that the rachis divides dichotomously as it does in most Australian species of *Thinnfeldia*.

Sphenopterid fragments.

Several sphenopterid fragments, which show no detail, may belong to a species such as *Coniopteris hymenophylloides* which is common in Jurassic floras, and is known in association with *Taeniopteris spatulata* in the Australian Jurassic.

Taeniopteris spatulata McClelland.

(Plate II., fig. 9.)

There is a considerable variety of leaves in the collection referable to *Taeniopteris*, examination of which only emphasizes the difficulty of accurate specific definition of numerous sterile *Taeniopteris* fronds (see Seward, 1904, p. 169).

These leaves are elongate lanceolate, somewhat strap-shaped, more than 7 cm. long, usually up to 1·6 cm. wide, occasionally somewhat wider (2·4 cm.), with a prominent finely-striated midrib which has a width of 1·5 to 2 mm. The secondary veins are at right angles, or almost so, to the midrib; many of them are simple, but many divide, usually only once, at varying distances from the midrib; on the average there are about 16 veins per cm. of lamina, but the number varies considerably, and in some of the narrower leaves there may be as many as 25 or 30 veins per cm.

It is not easy to separate these fronds from *T. spatulata* McClelland, and *T. spatulata* var. *major* (Seward). The larger specimens certainly approach *T. Carruthersi* Tenison-Woods, a species which has never been very satisfactorily described, since only incomplete specimens have been available. The midrib in the Western Australian specimens appears to be much more prominent than that of *T. Carruthersi*.

T. spatulata occurs abundantly in the Jurassic rocks of Eastern Australia, and occasionally in the Cretaceous. *T. Carruthersi*, on the other hand, appears to be a somewhat older form, occurring in the Triassic (Ipswich Series) of Eastern Australia, and in the Stormberg Beds of South Africa.

CYCADALES.

Ptilophyllum pecten (Phillips).

(Plate II., fig. 6.)

Specimens referred to *Ptilophyllum pecten* are quite similar to the many figured examples of this species which is widely distributed in rocks of Jurassic age. They are preserved as impressions on a fine-grained, ferruginous metaceous sandstone, and are not likely to furnish any details of cuticular structure. It therefore seems only possible to refer them to *P. pecten* (see Seward, 1917, p. 524). In Eastern Australia this species occurs in the Jurassic rocks at Stewart's Creek, Stanwell, Queensland, and in the Cretaceous rocks of the Maryborough Series and the Burrum Series.

CONIFERALES.

Elatocladus plana (Feistmantel).

(Plate II., fig. 7.)

Several specimens may be referred to *Elatocladus plana* Feistmantel, a common Jurassic type, of which Seward (1919, p. 431) has figured two specimens. The species has also been figured from Jurassic and Cretaceous rocks in Queensland (Walkom, 1917, Pl. 9, fig. 4; 1919, Pl. 2, figs. 4, 5).

The Western Australian specimens have linear leaves about 1.5 cm. long, with a distinct midrib.

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EXPLANATION OF PLATES.

Plate I.

Isoetites elegans, n. sp.

- Fig. 1. *Isoetites elegans*, n. sp. Specimen No. 16687. $\times \frac{1}{2}$.
- Fig. 2. Group of sporangia. Specimen No. 16683. $\times 3$.
- Fig. 3. Sporangium in position on basal portion of a leaf. Specimen No. 16682. $\times \frac{1}{2}$.
- Fig. 4. Single sporangium. Specimen No. 16711. $\times \frac{1}{2}$.
- Fig. 5. Portion of figure 4 enlarged to show triradiate ridges on megaspores. $\times 14$.



2



3



4



5

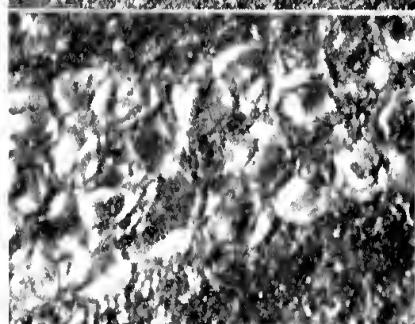


Plate II.

Fig. 6. *Ptilophyllum pecten* (Phillips). Specimen No. 16684. $\times 1$.
Fig. 7. *Elatocladus plana* (Feistmantel). Specimen No. 16703. $\times 1$.
Fig. 8. *Thinnfeldia talbragarensis* Walkom. Specimen No. 16690. $\times \frac{3}{4}$.
Fig. 9. *Taeniopteris spatulata* McClelland. Specimen No. 16685. $\times 1$.

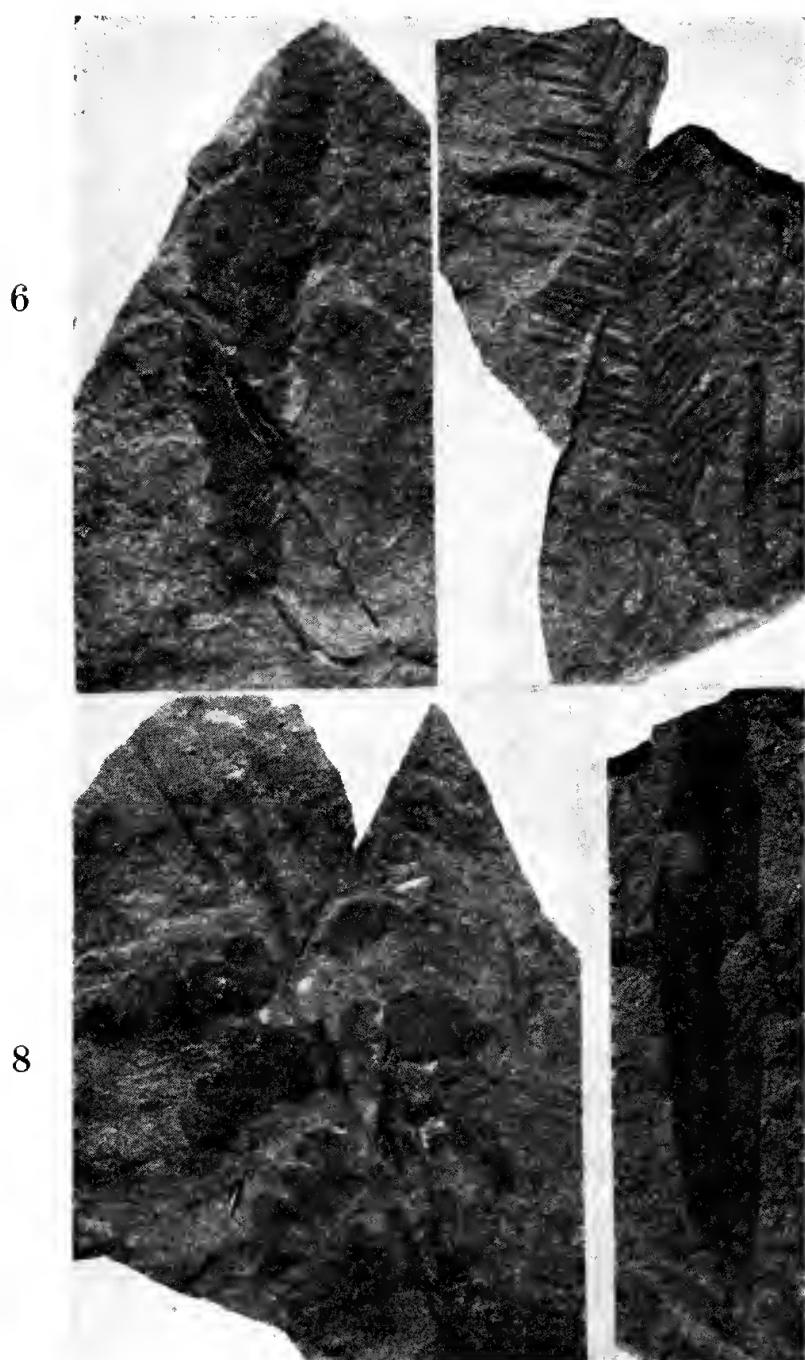
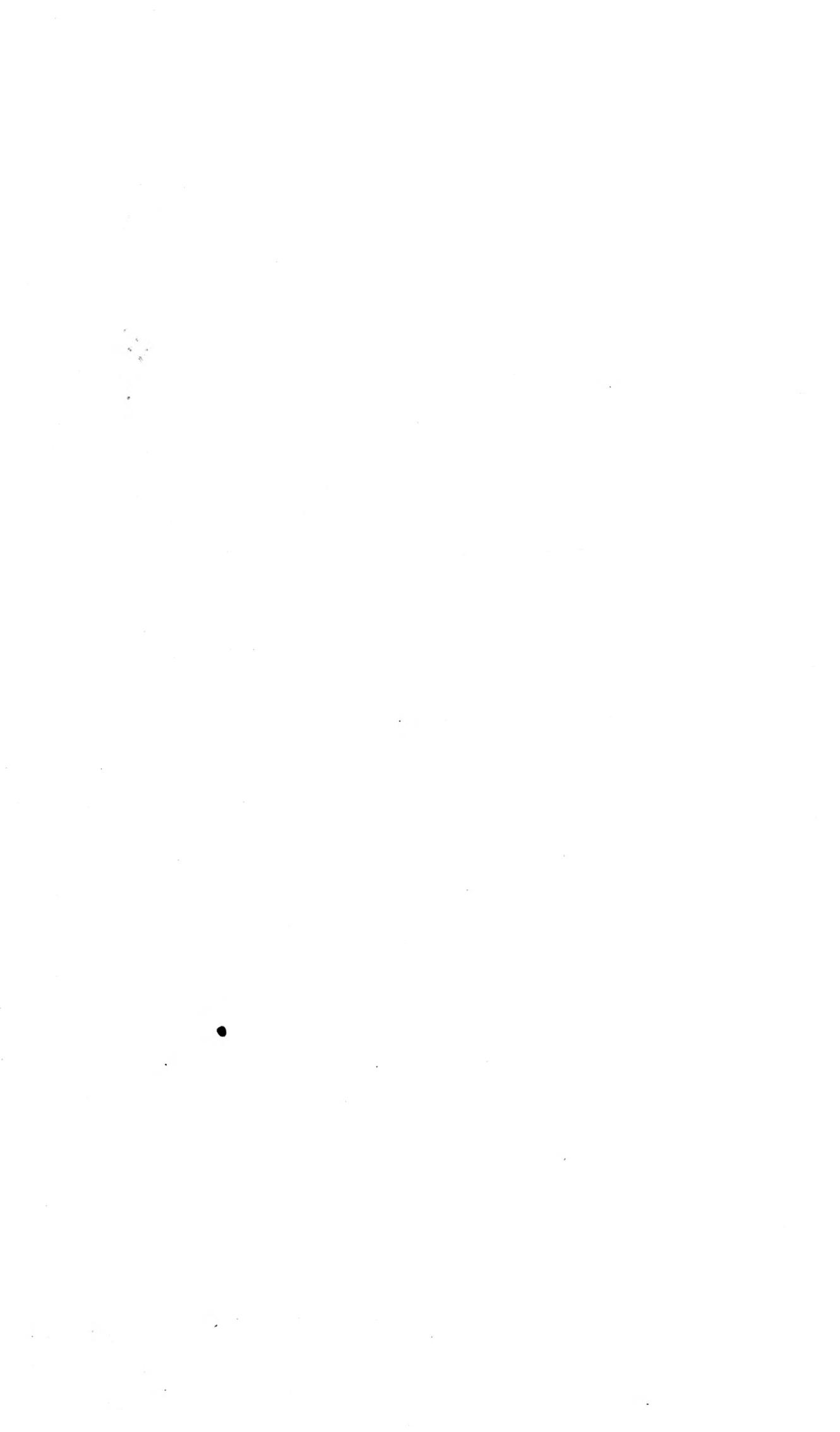


PLATE II.



11.—MARINE COPEPODS FROM WESTERN AUSTRALIA
SERIES II.

TWO PELAGIC COPEPODS FROM COCKBURN SOUND.

BY W. S. FAIRBRIDGE, B.Sc.

Read 14th April, 1942; published 27 March, 1944.

The species described were found in some plankton hauls made a few miles south of Fremantle in Cockburn Sound, about midway between Garden Island and the mainland. The maximum depth of water in the area is 20 metres.

Order CALANOIDA.

Family CENTROPAGIDAE Sars, 1902.

Genus CENTROPAGES Kroyer, 1849.

A large number of new species have been described since this genus was summarised by Giesbrecht and Schmeil (1898). Unfortunately, the author has been unable to study the descriptions of *C. longicornis* (Mori, 1932) and *C. ponticus* (Karawiew, 1895).

Centropages australiensis sp. nov.

Occurrence.—Regularly found, sometimes forming a considerable proportion of the catch; males and females in about equal numbers.

Female.—Length, 1·4–1·6 mm.

The mouth parts agree with those figured for *C. typicus* (Kroyer, 1848) by Giesbrecht (1892, Fauna und Flora des Golfes von Neapel) and Sars (1900, An Account of the Crustacea of Norway).

The fifth leg differs from *C. typicus* in the endopod, the second segment being as long or longer than the terminal and distinctly narrowed at the base, and the basal segment broadened distally. The second abdominal segment is very long compared with the genital and anal segments; the proportions of the abdominal segments are 23 : 34 : 10 : 18. The genital segment bears only two spines, one dorso-lateral and one ventro-lateral, both on the left side, the latter being very small; the second segment bears a hooked knob on its right side. The fifth thoracic segment is only slightly asymmetrical, the left side being the larger.

Male.—Length, 1·4–1·5 mm.

The first antenna has a distinct spine on segments 15 and 16 (Sars does not figure a spine on segment 15 for *C. typicus*, and Giesbrecht indicates a minute one); there is an incomplete division between segments 22 and 23 (as indicated by Giesbrecht for *C. typicus*, but Sars shows a complete division). The other mouth parts agree with those for *C. typicus*.

The swimming legs appear to be typical; Giesbrecht (1898) says of *C. typicus* that the right exopods of legs 3 and 4 bear a "vergrösserten Aussenranddorn" on the second segment; this is noticeable in the present species. The fifth leg differs markedly from *C. typicus* in that the basal portion of the chela is much narrower, resembling the type found in *C. hamatus* (Lilljeborg, 1853); and the proximal segment of the chela extends beyond the "thumb" and is but slightly hooked at the tip. The abdomen agrees with *C. typicus*. The spines of the last thoracic segment are asymmetrical, the right being much smaller than the left.

The specimens taken in Cockburn Sound appear to be identical with those found off New South Wales and figured by Dakin and Colefax (1940) as a variety of *C. kroyeri* (Giesbrecht, 1892) : the only difference between these specimens and the rather few figures given for the Sydney variety, being the slightly larger basal portion of the chela of the New South Wales specimens. While the male fifth leg of this species resembles *C. kroyeri* in some ways more nearly than *C. typicus*, the female abdomen and last thoracic segment are so entirely different from *C. kroyeri*, that it would seem best to regard it on these features as more nearly related to *C. typicus*. It resembles *C. typicus* rather than *C. kroyeri* in a number of other points : the spines on the proximal segments of the first antenna ; the outer spine of the second exopod segments of the third legs ; and the length of the inner spine on the second segment of the female fifth leg relative to that segment.

On comparison with some drawings made by Dr. A. G. Nicholls, this species appears to be identical also with a Centropagid found by him in 1939 at Crawley Bay in the Swan River. Crawley Bay is well up in the Swan Inlet, and the salinity would be very low in winter : this form is therefore either originally or secondarily estuarine. Dakin and Colefax give no details as to where their specimens were found, but all or most of their collecting was done in the open sea. Since therefore, this variety is constant from New South Wales to Fremantle, in the open sea and under estuarine conditions, it seems best to give it specific rank.

It may be most easily recognised by the female abdomen and the form of the chela of the male fifth leg.

Order HARPACTICOIDA.

Family TISBIDAE Sars, 1904.

Genus MACHAIROPUS Brady, 1883.

Lang (1936) has revised this genus. Since then two new species have been described : *M. antarcticus* (Lang, 1936b) and *M. intermedius* (Nicholls, 1941).

Machairopus cockburni sp. nov.

Occurrence.—8 females (3 ovigerous) and 10 immature specimens, in a horizontal haul at 10 m. depth ; 22°-7°-41°.

Female.—Length, 0·94-1·15 mm.

First antennae 9-segmented, tapering gradually, the proportional lengths of the segments being 18 : 24 : 32 : 18 : 4 : 4 : 3 : 10 : 14. Exopod of the second antennae 4-segmented ; the endopod bearing 9 terminal setae, 4 of which are geniculate. Second basal segment of the mandible bears a single, long, thick, plumose seta ; endopod and exopod typeal. Exopod of maxilla bears 2 long plumose setae ; the endopod with 3 stiff serrate setae ; inner lobe I with 8 setae, and inner lobes II and III each with 2 setae. First maxilliped with an inner marginal lobe bearing 2 stout and 1 fine plumose setae, and a slender distal lobe bearing 2 setae. Second maxilliped with 1 stout claw apically and 3 finer setae.

Proportional lengths of the segments of the endopod of the first leg 10 : 6 : 3, each segment with a plumose inner marginal seta ; outer marginal spine of the second segment of the exopod in the middle of the margin, and the inner marginal bulge pronounced. Seta formula :—

		Endopod.	Exopod.
p2	...	1. 2. 230	1. 1. 223
p3	...	1. 2. 330	1. 1. 323
p4	...	1. 2. 230	1. 1. 323

Distal segment of the fifth leg with almost parallel margins, and more than twice as long as wide ; it bears 3 terminal setae, the middle one longer than the other 2 ; 2 external lateral setae, each shorter than the terminals, the proximal being within the distal half of the segment. Proportional lengths of the abdominal segments and caudal rami 73 : 37 : 28 : 11 : 17. Genital segment deeply cleft ; caudal rami divergent, slightly wider at the base than long : the outer marginal seta barely within the distal half ; 4 terminal and 1 small dorsal setae.

Male.—Unknown.

This species most nearly resembles *M. hippolytes* (Kroyer, 1863), a northern cold-water species (Greenland and Norway), and *M. australis* (Scott, 1912), a southern cold-water species (South Orkneys and South Georgia). It differs from *M. hippolytes* in (a) the relative lengths of the segments of the first antennae, (b) the setae of the second basal segment of the mandible, (c) the setae of the inner lobe of the first maxilliped, (d) the relative lengths of the 2 proximal segments of the endopod of the first legs, (e) the setation of the swimming legs and, (f) the shape and setation of the fifth legs. In addition to the points (a), (b), and (e) above, it differs from *M. australis* mostly in the presence of a distal lobe on the first maxilliped, the shape of the fifth legs, and the length of the caudal rami to the anal segment (in *M. australis* "about as long as the last abdominal segment," Scott).

It may be recognised by the almost parallel margins of the fifth legs, the proportions of the endopod segments of the first legs, and the single large seta on the second basal joint of the mandible.

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PLATE I.

Fig. 1.—*Centropages australiensis*. ♀ Fifth leg.

Fig. 2.—*Centropages australiensis*. ♀ Abdomen (ventral).

Fig. 3.—*Centropages australiensis*. ♂ Abdomen (dorsal).

Fig. 4.—*Centropages australiensis*. ♂ Fifth legs.

Fig. 5.—*Centropages australiensis*. ♀ Abdomen (seen from left side),

Fig. 6.—*Centropages australiensis*. ♀ Abdomen (dorsal).

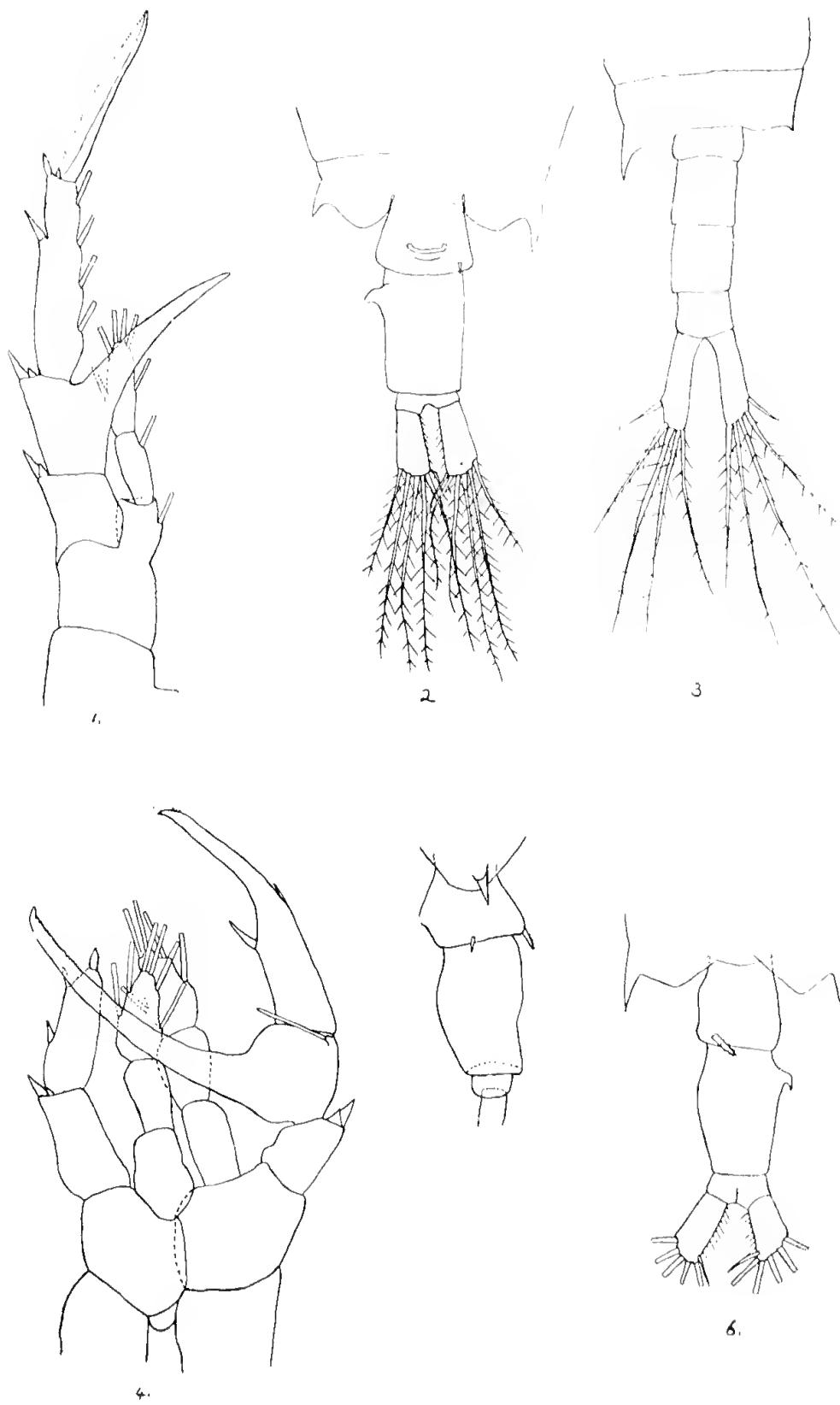


PLATE I.

PLATE II.

Fig. 7.—*Centropages australiensis*. ♂ Right antenna I.

Fig. 8.—*Centropages australiensis*. ♂ Fourth legs.

Fig. 9.—*Centropages australiensis*. ♂ Third legs (first and second Exopod Segments).

Fig. 10.—*Machairopus cockburni*. ♀ Fifth leg.

Fig. 11.—*Machairopus cockburni*. ♀ Abdomen (ventral).

Fig. 12.—*Machairopus cockburni*. ♀ Fourth leg.

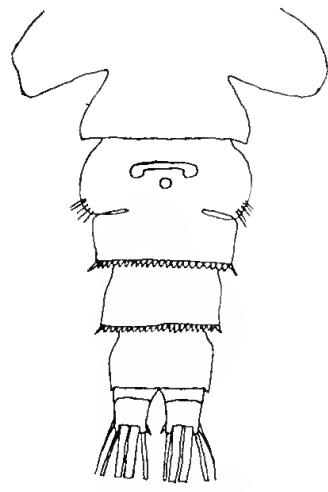
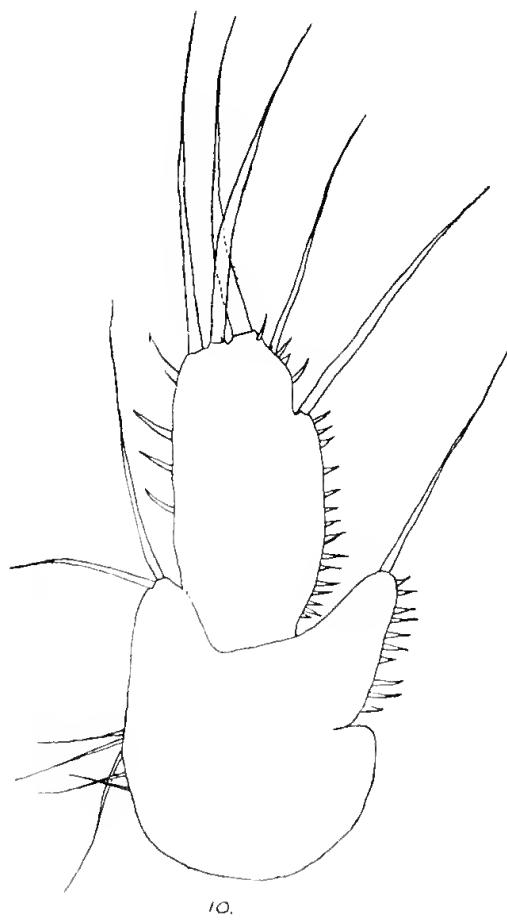
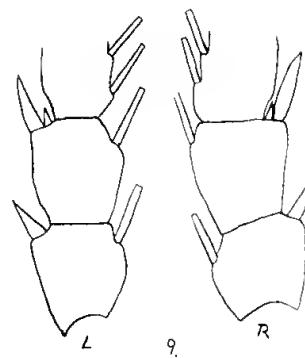
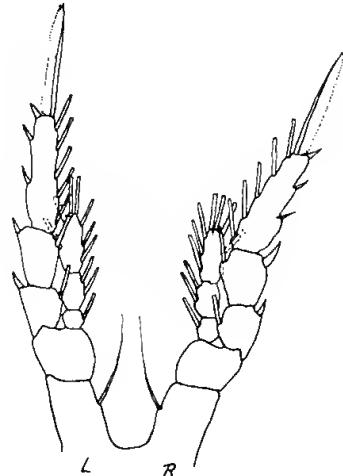
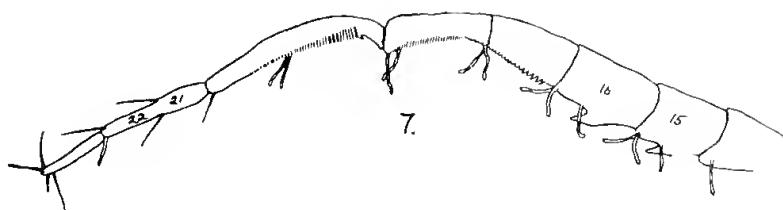


PLATE III.

Fig. 13.—*Machairopus cockburni*. ♀ Antenna I.

Fig. 14.—*Machairopus cockburni*. ♀ Antenna II.

Fig. 15.—*Machairopus cockburni*. ♀ Mandible.

Fig. 16.—*Machairopus cockburni*. ♀ Maxilla.

Fig. 17.—*Machairopus cockburni*. ♀ Maxilliped II.

Fig. 18.—*Machairopus cockburni*. ♀ Maxilliped I.

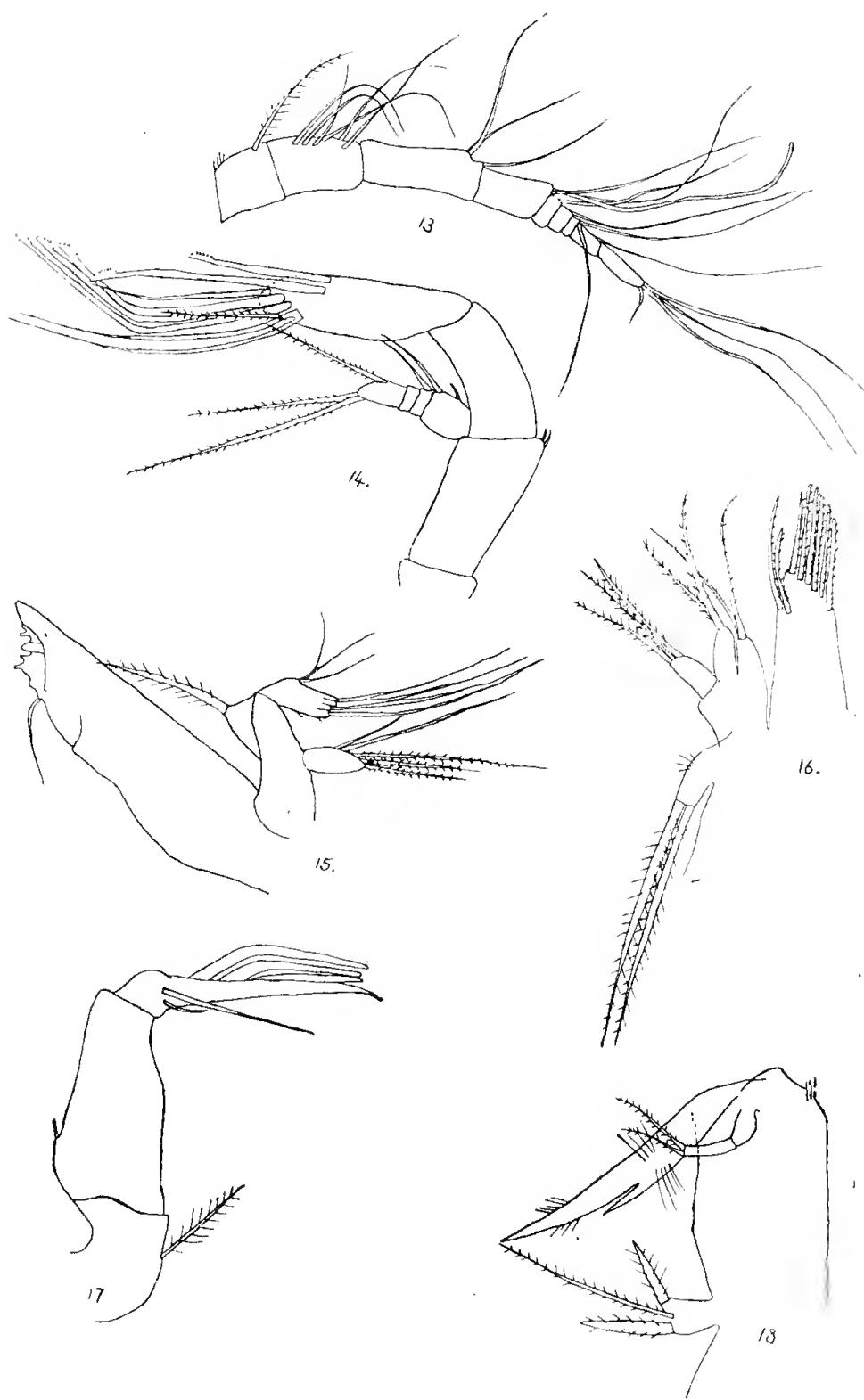


PLATE III.



12.—A CONSIDERATION OF THE INSECT POPULATION ASSOCIATED WITH COW DUNG AT CRAWLEY, W.A.

BY G. J. SNOWBALL, B.Sc. (Hons.)*

Read 9th June, 1942; Published 28th March, 1944.

1. INTRODUCTION.

The research work described in this paper is an attempt to indicate the main insects which form the population of cow dung at Crawley and to assign them to their proper place in the ecology of that substance. Most of the work was performed at the Biology Department, Crawley, during the periods February to November, 1940, and February, 1941, to February, 1942. Two cows supplied most of the dung utilised, but supporting observations at Maylands and Spearwood showed that this restricted amount of material indicated correctly the qualitative nature of the population, a conclusion borne out by the study of insects in the dung dropped by a herd of fifteen cows grazing in the grounds of the University. The writer also had the opportunity of examining cow dung from Armadale, and in August, 1941, was able to pay a visit to Katanning to make a rapid comparative survey of the cow dung population.

Katanning (latitude $33^{\circ} 38' S.$, longitude $117^{\circ} 35' E.$) has a climate of the continental type, characterised by a considerable variation between maximum and minimum temperatures. Perth (latitude $31^{\circ} 52' S.$, longitude $116^{\circ} 3' E.$) has a Mediterranean climate with less difference between the extremes of temperature. The rainfall at Katanning, although annually amounting to only about half that at Perth, is much more evenly distributed throughout the year, rainfall at Perth being essentially of the winter type.

Table 1.

The mean daily maximum and minimum temperatures, the mean daily relative humidity, and the mean annual rainfall at Katanning and Perth, Western Australia, for 34 years prior to 1932 (based on figures from the Weather Bureau, Perth):—

	PERTH.	KATANNING.
Maximum °C.	22.89	21.94
Minimum °C.	12.89	9.11
Humidity (%)	63	70
Rainfall (inches)	34.7	18.7

2. METHODS.

No accurate quantitative work was attempted in this general approach to the problem. The insects found in various cow dungs were submitted to experts for identification where possible and observations made on their habits. Portions of cow dung containing immature stages were brought into the laboratory for study of phases of the life histories of the insects concerned.

3. SUCCESSION.

A large number of insect species are associated with faecal matter, especially with that of mammals, which is usually of sufficient quantity to form an ecological habitat of some duration.

*In 1941 the writer was the recipient of a Hackett Scholarship, and in 1942 of a Hackett Studentship, for which his grateful thanks are due to the University of W.A.

In an unstable environment of a restricted nature, of which cow dung is an example, two main factors operate to influence the type of population present at any particular time. Firstly, the external climatic conditions change the nature of the environment, thus making it less suitable for the species which occupies it first. Secondly, the animals themselves, principally by interspecific competition, to a lesser extent by altering the physical and chemical nature of their environment, tend to bring about an alteration in the type of population. Ultimately a stage is reached at which a primary species is displaced by one more adapted to the changed conditions. The process continues until the environment is destroyed. This termination of the succession by destruction of the environment, which is characteristic of the animal ecology, serves to balance, in the broad cycle of energy of nature, the synthetic tendencies of plant successions in which a stable association is finally attained (Chapman, 1931).

The phenomenon of succession has received most attention from plant ecologists. The most clear cut examples of succession in animal ecology are found in certain restricted environments. The work of Graham (1925) on the succession of animals in a felled tree trunk may be cited here. He concluded that there was a definite succession of organisms as the chemical and physical characters of the wood changed during the process of decay and disintegration. Fuller (1934) found this statement to be equally true of the population of a carcass.

In the case of cow dung, the succession is not clear cut and only detailed study would reveal the causes of some apparent anomalies. The nature of the succession will be discussed after the insects concerned have been dealt with.

4. THE CHANGES IN COW DUNG AFTER DROPPING.

The initial nature of a cow dung varies considerably with the diet of the animal. The dung of a grass-fed cow differs from that of one fed on dried feed in its green colour, soft texture, and the subsequent course of its disintegration. The process of decay can be arbitrarily divided into five stages, of which the first three differ markedly from the last two. A characteristic insect population occupies the first three stages and a different one succeeds it in the last two. Certain distinctions can in many cases be drawn between the populations of Stages 1, 2, and 3, but equally often they are almost identical.

Following is the typical course of changes in dung from a grass-fed cow :—

1st Stage.

When dropped, the dung is green or more rarely tan in colour, semiliquid, and with a noticeable odour. Cow dung is characteristically a "cold" dung and high temperatures due to fermentation are unusual, especially in isolated cakes, although the temperature of the dung during the day may be high owing to exposure to the sun (Davidson, 1937). The slight degree of fermentation undoubtedly influences the insect population since certain insects, *e.g.*, the house fly, are specifically attracted to fermentable materials either by high temperatures or products of such decomposition.

The first obvious change in the cow dung is the formation of a thin blackish skin over the exposed surface of the soft mass. By evaporation of moisture, this skin ultimately becomes a thick, firm crust pierced by many cracks which expose the softer interior. The superficial skin is the result of an oxidation process dependent on free access of atmospheric oxygen, since it does not form on artificially covered cakes or those which for any reason are kept exceedingly moist.

2nd Stage.

The colour changes from tan or green to a light brown shade. The whole cake becomes firmer as a result of evaporation of moisture. The odour is still noticeable even when the surface remains unbroken.

3rd Stage.

The dung becomes blacker and firmer in texture. The fibres of the undigested food can be distinguished, because evaporation of moisture has concentrated the suspension of which they form the discontinuous phase. The odour is usually not noticeable unless the surface of the dung is disturbed.

4th Stage.

Evaporation of moisture has proceeded to the extent that undigested food fibres interlock to form a matrix firm enough for the whole cake to be held by the edge without breaking. The internal colour is a dull rusty brown. The surface layers of the dung are completely dry and of a bleached brown or even white colour due to the precipitation of salts.

5th Stage.

The entire dung becomes of the same nature as the upper portions of a fourth stage dung. It is firm, bleached brown, in some cases almost white, dry, hard, and noticeably light for its volume. In the later part of this stage no insects except casual shelterers are present.

A number of variations from the above cycle are possible. All parts of a dung cake do not necessarily pass through the same stage at the same time. For instance, dungs which have the upper layers in the fourth, and lower portions in the second or third stage, are common. Further, the changes in colour, texture, and moisture do not always proceed at the same rate. Dungs sometimes preserve the initial green colour although in other respects they could be classed as in the fourth stage. Such peculiarities are due to some unusual feature in the history of the cake, such as freedom from invasion by insects or conditions which artificially preserve the moisture content.

An important departure from the cycle outlined above is the omission of either the second or the third stage. The colour of a dung may pass straight from green to black, *i.e.*, direct from first to third, or from light brown to dark brown, *i.e.*, from second to fourth. In such cases, the population of the omitted stage is found in the early part of the third or late part of the second according to whether the second or third has been reduced.

In the field, large numbers of dungs disintegrate before they reach the fifth stage, an occurrence very frequent during the height of the summer.

The time taken to pass through the various stages of decomposition varies greatly with climatic conditions, so that, except within wide limits, the absolute age of the dung has little significance. High temperatures speed up the process of disintegration by accelerating the chemical and physical processes within the dung and by stimulating the contained insects. Rain has the reverse effect, and the stages of a dung exposed to rain may be indefinitely prolonged.

The following table indicates a few variations in absolute time of stage duration for various conditions of rainfall and temperature:—

Table 2.

Duration in days of each separate stage numbered.

Date of Dropping.	1.	2.	3.	4.	5.	Rain during period of disintegration.	Temperature during period of disintegration.	
20-3-41	...	1 ⁸ 2 ⁴	+	1 ³ 8	7	*	Nil	20.6° C.
2-4-41	...	2	+	10	15	*	2.84"	18.0° C.
7-4-41	...	1	+	3 ¹ 2	10	*	1.50"	17.6° C.
31-5-41	...	4	8	14	*	...	7.07"	14.2° C.
4-6-41	...	8	7	29	40	*	20.00"	13.9° C.
12-6-41	...	9	†23	...	41	*	17.14"	13.9° C.
22-6-41	...	7	18	*	...	...	5.52"	14.2° C.
23-7-41	...	8	3	29	*	...	6.86"	13.9° C.

* Broken up in this stage. †23 Duration of stage 2 plus 3 because they could not be separated. ‡ Omitted.

Insects are rarely responsible for the complete destruction of a cow dung, this being accomplished by rain and other mechanical agencies. On the other hand, cakes may remain in the fifth stage for years without noticeable erosion.

The cycle in a dung heap is substantially the same as that in a single cake, although the duration of the stages is usually greater because the inner portions are less accessible to disruptive influences.

5. THE INSECTS CONCERNED.

The following is a list of the Insect Species associated with cow dung at Crawley, Western Australia:—

Collembola	F : Hypogastruridae	F : Staphylinidae
	* Unidentified specimens	Creophilus erythrocephalus, Fab.
Dermaptera	F : Labiduridae	* Cryptobium elegans, Blkb.
	Unidentified species	* Leptacinus socius, Fauv.
Orthoptera	F : Tettigoniidae	Philonthus sp.
	Unidentified specimens	Oxytelus spp.
	F : Grylloidalpidae	F : Silphidae
	Cylindracheta sp.	? Choleva sp.
Hemiptera	F : Pentatomidae	F : Trichopterygidae
	Unidentified specimens	? Epoptia sp.
	F : Coccoidae	? Philagaria sp.
	Unidentified specimens	F : Histeridae
Coleoptera	F : Carabidae	Saprinus incisus, Er.
	Promecoderus albanyensis, Cast.	Saprinus spp.
	F : Hydrophilidae	Ulster walkeri, Lea.
	* Cercyon haemorrhoidalis, Fab.	Platysoma ? multistriatum, Lea.
	* Cercyon nigriceps, Marsh.	F : Nitidulidae
	? Paracymus sp.	Carpophilus hemipterus, Linn.
		? Brachyepheus sp.
	F : Colydiidae	F : Colydiidae
	Pabnla dentata, Blkb.	Pabnla dentata, Blkb.
	F : Ptinidae	F : Ptinidae
	? Pthms sp.	? Pthms sp.

* Breeding in cow dung.

F : Scarabaeidae	F : Otitidae
* Aphodius lividus, Oliv.	* Chrysomyza aenea, Fab.
Aphodius insignior, Blkb.	Pogonortalis barbifera, Macq.
Aphodius granarius, Linn.	
Aphodius ambiguus, Boh.	
Aphodius sp.	
* Proctophanes sculptus, Hope.	
Ataenius ? integricollis, Lea.	
Ontophagus ferox, Har.	
F : Anthicidae	F : Calliphoridae
Anthicus hesperi, King.	Calliphorinae
F : Tenebrionidae	Calliphora (Neopollenia) australis, Boisd.
Gonocephalum arenarium, Fab.	Calliphora (Proeckon) nociva, Hardy.
Adelium scytalicum, Pasc.	Lucilia cuprina, Wied.
Diptera	Sarcophaginae
F : Psychodidae	* Sarcophaga (Parasarcophaga) depressa, Desvoidy
* Psychoda spp.	
F : Sciaridae	F : Muscidae
* Sciarra spp	Muscinae
* ? Zygoneura sp.	* Musca vetustissima, Walker.
F : Scatopsidae	* Musca domestica, Linn.
? Rhegmoclemia sp.	Anthomyiinae
F : Mycetophilidae	* Hylemyia deceptiva, Mall. or near
? Mycetophila sp.	* Hylemyia sp.
F : Tipulidae	Fanniinae
Eriopterinae	* ? Fannia sp.
* Unidentified species	
F : Stratiomyidae	Phaoniinae
Neoexaireta spinigera, Wied.	* Helina hypopleuralis, Mall. or near
F : Dolichopodidae	* Helina coerulescens, Stein.
? Asyndetus sp.	* Helina regina, Mal. or near
F : Phoridae	* Rhynchosmydaea (Hardyia) carinata, Stein or near
? Chaetocnemistoptera sp.	* Muscina stabulans, Meig.
F : Sepsidae	
* Sepsis plebeia, de Meij.	Lepidoptera
* Australosepsis fulvescens, Mall.	F : Oecophoridae
* Australosepsis fulvescens var.	* Unidentified species
atratula, Mall.	
F : Borboridae	Hymenoptera
* Leptocera spp.	F : Alysiidae
F : Drosophilidae	1 unidentified species
* ? Cladochaeta sp.	F : Figitidae
	1 unidentified species
	F3 : Forficulidae
	Unidentified species

6. RELATIONS OF INSECTS TO THEIR ENVIRONMENT AND TO EACH OTHER.

These may be outlined as follows :—

1. Those which do not live in the cake itself but use it as food, e.g., blowflies, Coprine beetles.
2. Predators on dung insects with no closer relationship to the dung. These usually remain on the outside of the cake, e.g., Dolichopodids, *Greophilus erythrocephalus*, and ants.
3. Those which live in or on the dung, but subsist on the fungal growths which it supports. Probably the minute Collembola frequenting dung have this habit, although their small size renders the elucidation of this point very difficult.
4. Insects, the larval stages of which live in and feed upon dung while the adults have other feeding habits, e.g., some Sarcophagids and probably *Neoexaireta spinigera*.
5. Insects which are predatory themselves or have predatory larvae and of which the whole life history is passed within the dung, e.g., *Oryctelus*, *Leptacinus*, *Cryptobium*, *Saprinus*, and *Platysoma*.

6. Insects which use the dung as a shelter, e.g., Pentatomida, Dermaptera, and Tenebrionids, the association of which with the rest of the cow dung population is only of the most casual nature. Ants are in this class but they are also predatory.
7. The true dung insects, which are coprophagous and pass through their entire life history in the dung, e.g., the Aphodii. Owing to a doubt concerning the food of the larvae of the Cercyons, it is not known whether they can be classed here.
8. Parasites of dung-living larvae, e.g., Alysiids and Figitids.

7. NOTES ON THE INSECTS ASSOCIATED WITH COW DUNG AT CRAWLEY.

Order 1—COLLEMBOLA.

Myriads of minute blue insects belonging to the Hypogastruridae occur in and on dung during the winter, June to August. Large numbers occur in any stage of the dung providing it has remained fairly moist.

The whole life history can apparently be passed through in cow dung. Eggs are fairly common in the dung, most noticeably so in June. Some brought into the laboratory in June, 1941, hatched in twelve days, but the insects were not raised to maturity. At times, parts of first and second stage dungs in the field are almost white with the exuviae of these tiny insects.

Order 2—DERMAPTERA.

Unidentified specimens of Labiduroid Dermaptera are occasionally shelterers under cow dungs in the field. The association with the dung appears to be nothing more than casual.

Order 3—ORTHOPTERA.

Tettigoniid nymphs are sometimes found sheltering under old cow dung, while a *Cylindracheta* species found at Crawley is apparently capable of a truly coprophagous habit, since two specimens lived for some weeks on a diet of pure cow dung.

Order 4—HEMIPTERA.

At Katanning in August, 1941, a number of Pentatomids were collected in crevices of very old fifth stage dungs which they used as a shelter only. The same is true of Coccid nymphs found under old dungs at Spearwood, Western Australia, in April, 1941.

Order 5—COLEOPTERA.

F. 1. CARABIDAE.

Promecoderus albanyensis, Cast.

Specimens of this wingless beetle occur under cow dung at Crawley. It is presumably predaceous but its timidity has so far prevented observation of its habits.

The larvae of unidentified Carabs are also common under, and more rarely in, dung cakes. One was kept alive during August and September, 1941, on a diet of Sepsid and Sciarid larvae, but died before pupating.

F. 2. HYDROPHILIDAE.

The genus *Cercyon* contains both aquatic and terrestrial species, many of the latter being inhabitants of dung, Stephens (1839) having described

42 species with this habit. *Sphaeridium*, a coprophagous genus which I have not seen recorded from Australia, is associated with *Cercyon* in both England and France, especially in cow dung (Laeordaire, 1854), and in Ceylon and Japan aquatic species of both occur (Sharp, 1884, 1890).

***Cercyon haemorrhoidalis*, Fab.**

This introduced species is represented at both Crawley and Katanning by two easily separated varieties. One is most numerous between November and June (Pl. 1, Fig. 1), the other between June and November, both being present all the year round. The species occurs also in carrion, decaying grass, and horse manure.

With the Aphodiines, Staphylinids, and Histerids, they arrive at the dung soon after dropping, the odour being apparently the attracting stimulus. At first they congregate on the under surface or in the natural cracks of the dung. From these vantage points the work of penetration begins. The adults are coprophagous, and tunnelled out dung is eaten, since no waste is found outside infested cakes. The area of penetration is peripheral at first, then the insects concentrate on the upper surface. Many dungs are found with an almost unaltered core, though the superficial layers are completely penetrated underneath the firm outer crust which is pierced by numerous holes.

Under favourable conditions of fine days and high temperatures cakes may be riddled into a bran-like mass in a single day. Where heavy rain has fallen or low temperatures prevail, the process of penetration may be greatly slowed down, and may not even occur to any extent at all.

The specimens of *Cercyon haemorrhoidalis* run into dark places only when a dung is disturbed, and are otherwise tolerant of light.

The beetles leave the dung after a varying period, which is generally from four to fourteen days. It may be much longer and fluctuates considerably from cake to cake under identical external conditions. During this period, which is one of trophic activity, eggs are deposited, since larvae begin to appear in the third stage dung. I have not been able to isolate the eggs of the species in spite of the larvae being fairly plentiful. Numbers of females eaged with dung in the laboratory died without oviposition, yet dissection showed their ovaries contained numerous oocytes.

Exactly what the legless mandibulate larva (Pl. 1, Fig. 2) feeds on is a problem. The gut contains a translucent reddish-brown liquid full of oil globules which cannot certainly be recognised as a derivative of cow dung. Development occupies approximately 10 to 14 days in pure cow dung.

Pupation generally occurs in the dung itself in a small cavity excavated by the prepupa near to the outer surface. Where the dung has remained very moist, pupation may occur in the sand below the dung. No cocoon of any sort is formed. The pupae are of the usual exarate coleopterous type and, like many other white or yellow immature stages of insects, is negatively phototropic.

The pupal period was observed to range from three days in April (18° C.) to 11 days in September (13.9° C.). The life cycle from egg to adult took less than 29 days at temperatures from 13.9° C. to 16.1° C. in September and October, 1941.

There is an indefinite number of generations per year, as larvae and pupae occur in numbers at Crawley for most of the year except for a marked pause in June and July, when only occasional ones are found. Owing to the comparatively short duration of stages suitable to *Cercyon* larvae, a second generation never develops in any one dung cake.

***Cercyon nigriceps*, Marsh.**

This small species is associated with *C. haemorrhoidalis* at Crawley and Katanning, though always in small numbers. Its life history and habits are similar to those of its larger relation.

? *Paracymus*, sp.

A number of small beetles taken in cow dung at Crawley in April, 1941, probably belong to this genus. Their rarity indicates that they are of little importance in the dung community.

F. 3. STAPHYLINIDAE.

***Creophilus erythrocephalus*, Fab.**

On warm days at most times of the year specimens of this beetle gather on fresh dung cakes to catch Sepsids and Borborids attracted to it. Usually they remain on the outside of the cake, but may retreat into cracks if disturbed, or even hollow out cavities on its lower surface. According to Fuller (1934) they attack immature stages of sheep blowflies breeding in carrion, without appearing in sufficient numbers to have much effect on the maggot population of a carcass. This is also true of the dung cake, as rarely more than six specimens will be found on the one pad, which means that only a small percentage of the myriads of flies which foregather are destroyed. *C. erythrocephalus* rarely remains after the decline in number of flies consequent on the formation of a superficial crust on the cake. Because of this it is not known whether it will attack dung-inhabiting larvae.

***Philonthus*, sp.**

An unidentified species of this genus is occasionally found in small numbers, usually in second or third stage cow dung. It is more numerous in decaying grass. Fuller (1934) states that *P. Politus*, Linn. eats eggs and young larval blowflies in carrion. The genus is common in England, where four species are recorded by Stephens (1939), mostly in dung, and it is represented in New Zealand (Broun, 1880).

***Leptacinus socius*, Fauv.**

This species, which is presumably predaceous on small Dipterous larvae, is present in numbers less than the *Cercyons* throughout the year in cow dung of all stages, mainly in the first and third. It was not seen at Katanning in August, 1941. Although Staphylinid eggs and larvae are common in fourth stage dung, attempts to obtain adults failed. The larvae of *Leptacinus socius* may leave the dung to pupate because in September, 1941, pupae were found in the sand under an 81 day old dung kept in the laboratory since dropping. Dung from Armadale collected in March, 1941, contained a pupa (Pl. 1, Fig. 3) of this beetle actually in the dung itself.

The pupal period under laboratory conditions was found to be in the region of 26 days at an average temperature of 13.9° C. in September, 1941.

Cryptobium elegans, Bilk.

This species is associated with *L. socius*, but nothing of its life history is known. The genus is represented by 20 species in England, 19 of which live in dung and similar material (Stephens, 1839).

Oxytelus, sp.

Several unidentified species are numerous in cow dung, sometimes greatly exceeding *Leptacinus* and *Cryptobium* in numbers. They are among the first to colonise freshly dropped dung, especially if it has been scattered in a number of shallow pieces. They also occur in numbers in carrion. In northern Australia they may play a part in reducing the incidence of the Buffalo Fly (*Lyperosia exigua*, de Meij) by competing with its larvae in cow dung (Mackerass, 1932).

The only immature stage seen was a single exarate pupa in September, 1941, in the sand under dung, three months old, kept in the laboratory since dropping.

F. 4. SILPHIDAE.

Only two specimens, probably belonging to *Choleva* sp., were collected from third stage cow dung at Crawley in March, 1941, and hence the family is unimportant in the succession. Two species of *Choleva* occur in carrion (Fuller, 1934).

F. 5. TRICHOPTERYGIDAE.

At Crawley, species near *Epoptia* and *Philagarica* in cow dung in all stages, especially in the fourth if it is not too dry. Their habits are not known. The family is best represented in the tropics, occurring in rubbish, leaves, under bark or in rotten wood (Lefroy, 1923).

F. 6. HISTERIDAE.

Members of this family are present in cow dung at Crawley between October and May, although they are found in carrion and decaying grass at other seasons of the year.

SAPRINUS.

Two species of this genus occur in cow dung of which only one, *S. incisus* Er., has been identified. Both exhibit a preference for fresh cow dung and tolerate excess moisture better than do the Hydrophilids.

They never remain in the dung beyond the third stage, which is the one containing the majority of their prey, larvae of Sepsids, Drosophilids, and probably Borborids. Small quantities of dung are also eaten. Three larvae were found in fourth stage dung brought from Armadale to St. George's College in March, 1941. One of these subsequently pupated; the adult emerging after three weeks at an average temperature of 18° C.

The genus *Saprinus*, like other insects in decaying materials, is widespread. Species of it occur in England (Stephens, 1839), New Zealand (Broun, 1880), and in carrion at Canberra (Fuller, 1934).

PLATYSOMA.

One specimen of *P. ? multistriatum*, Lea, was collected in second stage cow dung on 4th March, 1941. Stephens (1839) describes three species in England all under bark.

HIST R.

H. walkeri, Lew., is the largest of the dung-frequenting beetles at Crawley. It is most numerous from October to April. It is frequently found in quiescent state in the moist sand below a cake and is not often found inside. In this it differs from *H. coenosus*, which in Haiti is such an efficient predator on Muscoid maggots in fresh moist dung that Myers (1938) has recommended its introduction into Australia as a possible control of the Buffalo Fly.

The local species is also predatory on maggots. It probably takes up its characteristic position in order to catch maggots which come to pupate on the lower surface of the cake. Unlike *Saprinus*, it may occur with fourth stage dung.

Hister is represented in England and New Zealand.

F. 7. NITIDULIDAE.

One specimen of *Carpophilus hemipterus*, Linn., which in California is an important pest of fresh and dried figs (Simmons, Reed, McGregor, 1931), was collected from second stage dung in September, 1940. If due to anything but chance, its presence indicates a considerable departure from the usual habits of the species. In April, 1940, two specimens of ? *Brachypeplus* sp. were also found in dung of the same stage.

F. 8. COLYDIIDAE.

Three specimens of *Pabula dentata* Blkb. were obtained from cow dung in April, 1941. The members of the family are generally found in leaf mould, decaying wood or under bark (Tillyard, 1926).

F. 9. PTINIDAE.

In May, 1941, a single specimen of ? *Ptinus* sp. was found in a dry, bleached fifth-stage pad. Its presence, if not merely fortuitous, adds yet another food material to the remarkable list given for the family by Esdaile (1927)—farinaceous matter, drugs, books, tobacco, spices, pepper, and wood.

F. 10. SCARABAEIDAE.

APHODIUS.

Aphodius lividus Oliv.

This species has a world-wide distribution (Schmidt, 1922). With *Ataenius stercoreator* it is abundant in Puerto Rico, where the two eat so much of the fresh cow dung that the larvae of the Horn Fly (*Lyperosia irritans*) can scarcely live. (Observations quoted by Myers, 1938). Myers, however, states that in Haiti these beetles have little effect on the population density of the Horn Fly. *A. lividus* occurs in large numbers at Uvalde, Texas, U.S.A., where 1,113 specimens have been collected from a single dropping (Lindquist, 1935). Though not yet finalised, sampling counts at Crawley indicate that greater numbers per cake are not unusual here. Stephens (1839) includes it in his list of fifty-seven English species of *Aphodius*, nearly all of which occur in dung. Boucomont (1929) reports its presence in dung in China. At Crawley it forms a prominent part of the population of both horse and cow dung and is present at Katanning. At Crawley it appears at and enters the dung shortly after dropping, leaving again at some time in the third stage. All feeding stages are coprophagous.

The actual information on the life history of *A. lividus* is slight and much of it must be conjectured. This is due to the slow growth of the larvae and the difficulty of handling them under laboratory conditions. Eggs and larvae of Scarabs are numerous in cow dung at Crawley, but strangely enough most of them are those of *Proctophanes sculptus* Hope, the adults of which are much fewer in number than those of *A. lividus*.

Scarab eggs are common in fourth stage dung from February to August. Eggs have been kept in the laboratory up to 11 days before hatching. This represents less than the minimum egg period since none were actually collected immediately after laying. Although Scarab larvae are adapted to the firm, rusty-brown dung of the fourth stage, they sometimes occur in the moister, fresher dung of the third.

The life history period from the egg to the emergence of the adult was found to be as short as 45 days during March (average temperature 20.6° C.) and April (18.6° C.), 1941. Three larvae which pupated in April emerged in May after pupal periods of fourteen to sixteen days. It seems that under certain circumstances the period of development from the egg to the adult can be considerably shorter than that of *A. tasmaniae*, which is approximately one year (Swan, 1934). Lindquist (1935) estimated the life history period of *A. lividus* to be 25 to 45 days at Uvalde, U.S.A. under laboratory conditions.

Pupation usually occurs in the sand below the dung., the pupa (Pl. 1, Fig. 4) being unprotected by any cocoon structure.

It is probable that the species breeds in other media besides cow dung, since the larvae seen were very few compared with the large number of adults.

Aphodius insignior, Blkb.

Blackburn (1904) created this species from specimens taken near the Swan River, and Schmidt (1922) only gives Western Australia as its area of distribution.

No representatives were found at Katanning in August, 1941. At Crawley they show a remarkable seasonal distribution. Up till June, 4, 1941, no specimens had been collected since August, 1940. On that date one specimen was discovered in a second stage cow dung. On 16th June, following rain, myriads appeared, swarming in fresh dung near the Biology Department. They practically excluded all other beetles and burrowed even into the most liquid cakes. The large numbers were maintained until the end of July when a decline set in. By 30th August they had again disappeared.

This appearance in large numbers suggests that *A. insignior* has a life history similar to that of *A. tasmaniae*, which has an annual emergence of adults over a short period of the year. As no immature stages of *A. insignior* have so far been found, this must remain conjectural for the present.

The species exhibits a marked preference for fresh, greenish dung on which it feeds freely. The beetles are exceedingly tolerant of moist conditions, which gives them a considerable advantage over other insects in colonising cakes. When inside the dung or on it they habitually associate in pairs. Hanging on to the prothorax of the female with its forelegs, the male is carried round on her back and requires considerable persuasion to dismount. This habit is no doubt a prelude to mating, though actual copulation has not been observed.

A. insignior rarely remains on the dung beyond the second stage.

***Aphodius granarius*, Linn.**

This world-wide species is present both at Crawley and Katanning in horse and cow dung. Its small numbers preclude its being of much importance in the succession.

***Aphodius ambiguus*, Bohem.**

Also known as *A. frenchi* Blkb, this species is widely distributed in Africa and Australia (Lea, 1923). Its importance in the dung community varies greatly at Crawley and Katanning. At Crawley, specimens are most numerous in the period May to August, the total range being from mid-April to October. Their numbers are always far short of those of *A. lividus* or *C. haemorrhoidalis*. They appear beneath the fresh dung, where they remain until the majority of the other dung-invading beetles have left. By this time the dung has usually attained the fourth stage. The beetles then commence to migrate inside. This well marked succession of the species to the others is a feature of the winter cycle in dung. In many cases they remain quiescent on the lower surface without entering the dung. While they have never been seen feeding, the gut contents indicate that dung forms the staple food. At Crawley they also frequent rotting bark, carrion, and decaying grass.

At Katanning in August, 1941, a different state of affairs was seen. Instead of being in the minority, they far exceeded all the other dung-frequenting beetles in number. As at Crawley, they tended to remain on the lower surface of cakes of all stages though numbers had penetrated even into fresh dung.

Nothing is known of the life history of *A. ambiguus* in spite of the presence of numerous females with well-developed oocytes in their ovaries. Possibly some of the Scarab larvae found in the cow dung belong to this species.

***Proctophanes sculptus*, Hope.**

This bulky beetle occurs all the year round at Crawley, becoming most numerous in the period May to August. Its position in the succession is difficult to estimate as it frequently occurs associated with *A. ambiguus* but also singly in very fresh and more rarely in dry fifth stage dung. Both larvae and adults are eophrophagous.

Owing to the length of the life history and the fierce competition offered by Seiariid larvae under laboratory conditions, the information on it has been collected only from a few cases. Seven specimens were reared from the egg during the period June to November, 1941, and the length of the period from hatching to emergence of the adult ranged from 97 to 157 days.

The eggs, which are scattered singly in fourth stage dung, hatch about 12 days after laying. The pupal period is approximately three weeks, the pupae being found in the sand under the dung. The larval period is thus shorter than that of *Aphodius tasmaniae* (Swan, 1934), which takes from April to December. The larvae *Proctophanes* may remain in a quiescent non-feeding state for as long as 48 days prior to pupation.

***Ataenius* ? *integrifollis*, Lea.**

In August, 1940, three specimens were collected in cow dung at Crawley, the species having been described from Queensland (Lea, 1923B). Specimens of an unidentified species of *Ataenius*, two at Crawley in December, 1941, and one at Dog Swamp, Tuart Hill in January, 1942, were taken from cow dung. According to Blackburn (1904) the Australian species of *Ataenius* are probably numerous. Considerably more of them came to his notice than all the described

Aphodii of Australia at the time of writing his paper. In view of this statement and the association of species of *Ataenius* with *Aphodius lividus* in other parts of the world (Myers, 1938; Lindquist, 1935), the paucity of *Ataenii* at Crawley is surprising. None were found at Katanning in August, 1941.

Sub-Family COPRINAE.

Although they play no part in the succession in cow dung, Coprine dung beetles are of interest because of their habits, which have made them the subject of study from the earliest times. The ancient Egyptians regarded the manipulations of circular dung pellets by *Scarabaeus sacer* as a symbol of the revolution of the planets, and its periodic appearance and disappearance as a sign of eternal life. The Coprinae utilise dung as food for themselves and their larvae without actually living in it. This interesting group is not as well represented in Australia as elsewhere and the species in general are smaller (Lea, 1923A). The chief Western Australian genus is *Onthophagus*, which contains 10 English species found in dung (Stephens, 1839), while Lea (1923A) lists 102 Australian, of which two, *O. nitidor* Blkb. and *O. australis* Gner., frequent carrion at Canberra (Fuller, 1934). One specimen only has been found at Crawley, but *O. ferox* has been taken at Belmont and Claremont, while in the country it occurs at Katanning and at Capel.

Onthophagus ferox digs vertical shafts in close proximity to or under cakes of dung. At about a depth of four inches the direction changes to the horizontal, the resulting passage being about three inches long. In the blind end of this the store of dung is placed. Fresh pig, sheep, cow or horse dung is used and stored in the form of scraps, not moulded into pellets. The excavator of the tunnel is usually found at the bottom of the vertical shaft during the day, the digging apparently being performed at night. There was no indication that the beetles work in pairs as is the case with *Copris lunaris* (Wheeler, 1922). The presence of *Onthophagus* is indicated by piles of turned-up earth round the edges of dung cakes.

F. 11. ANTHICIDAE.

In March, 1941, two specimens of *Anthicus hesperi*, King, were collected from cow dung at Crawley. This maintains the relationship between carrion and dung insects, since *A. hoeferi*, Kerg, is a carrion insect at Canberra (Fuller, 1934).

F. 12. TENEBRIONIDAE.

Gonocephalum arenarium, Fab., and *Adelium scytalicum*, Pasc., are present at Crawley as shelterers under old, dried fifth stage cow dungs.

Order 6—DIPTERA.

F. 1. PSYCHODIDAE.

These tiny moth-like flies are commonly associated with decaying vegetable matter, dung or water. Some species of *Psychoda* breed in drain pipes, the larvae being able to survive hot water and soap (Curran, 1934). The family is widespread. *Pericoma* has been bred from horse and cow dung in Denmark (Thomsen & Haunser, 1936), *Psychoda minuta* from cow dung at Washington (Howard, 1912). Two species of *Psychoda* frequent carrion at Canberra (Fuller, 1934). The economic importance in Australia is negligible apart from occasional nuisance caused by large numbers getting into exposed food material.

At Crawley there appeared to be two species of *Psychoda*, a common grey one and a rarer white. From May to October the larvae, pupae, and adults of grey species occur on and in soft, moist, first to third stage cakes, especially those in the shade. Both larvae (Pl. 1, Fig. 5) and pupae have respiratory siphons which are apparently responsible for the high moisture toleration.

At the time of pupation the larvae come to the surface. The cracks of a cake may be packed tight with the naked pupae. The total time of life history from egg to emergence of adult was 6½ days in September, 1941 (average temperature, 13·9° C.).

The Psychodidae breed in fresher dung than the Sciaridae and consequently precede them in the succession. In the same stage dung as Psychodid larvae and pupae, Sepsid and Drosophilid larva occur, followed later by Cercyon larvae.

F. 2. SCIARIDAE.

Though small flies belonging to *Sciara* sp. infest dung in the laboratory, they are not numerous in the field. The genus *Sciara* is world-wide, having been recorded from North and South America, Africa, Southern Asia, and New Zealand (Skuse, 1889). Tonnoir (1929) estimated the number of described species of *Sciara* and those in collections in Australia, at 63.

They can breed in a wide range of organic materials. Fuller (1934) records them from carrion. The author has bred them from rotting bark and decaying tea leaves. Almost any vegetable detritus which is moist and not exposed to intensities of light or strong air currents seems to suffice. The comparative rarity of these conditions at Crawley accounts for the small numbers of *Sciara* sp. in the field. They breed in late fourth stage dungs more or less sheltered and practically devoid of other insects.

The larvae (Pl. 1, Fig. 6) feed on dung which they comminute into a black powder only held together by moisture. This habit and their large numbers render them a great obstacle to the successful rearing of Scarab larvae in the laboratory. There are indications that they will even attack and consume Scarab pupae.

Pupation occurs in the dung without formation of a pupal cell or cocoon. The pupa has no respiratory processes, though these do occur in some species of *Sciara* (Gsten Sacken, 1862). The pupal period varies from two to five days.

Copulation takes place at an early stage, sometimes before the wings of the participants are properly unfolded. The whole life cycle from egg to adult required 10 to 12 days in June (average temperature, 14·5° C.) and July (13·6° C.), 1941. In Denmark, Thomsen and Hammer (1936) estimated the length of the life cycle of a species of *Sciara* to range from 19 to 22 days at temperatures of 19° to 22° C.

The only other Sciarid found at Crawley was a single specimen of ? *Zygo-neuro* sp. bred from cow dung in the laboratory in July, 1941.

In spite of their short life cycle and fecundity, the Sciaridae are rendered of minor importance in the succession in cow dung by the frailty of the adults and the restricted physiological requirements of the larvae.

F. 3. SCATOPSIDAE.

These flies are also associated with a variety of decaying materials. *Scatopse* sp. (? *pulicaria*) emerged from vessels containing pig, horse, cow, and calf dung in Denmark (Thomsen & Hammer, 1936), and a species occurs on carrion at Canberra.

At Crawley specimen of ? *Rhegmoclema* sp. emerged in large numbers in the period November, 1940, to April, 1941, from dung brought into the laboratory in November, 1940. In April, 1941, another batch came out of 39-day-old dung which also contained Scarab larvac. They have not been seen in the field and consequently have no place in the succession in cow dung outdoors.

They appear to breed only in late fourth and such fifth stage dungs as remain moist. Both the larva (Pl. 1, Fig. 7) and the pupa (Pl. 1, Fig. 8) show adaptations for living in poorly aerated, moist surrounding. Pupation occurs inside the last larva's skin.

A number of adults dissected in February and March, 1941, contained as many as six to eight nematodes, each in the abdominal region. The parasites must have occupied the greater part of the space of the abdomen.

F. 4. MYCETOPHILIDAE.

A single specimen of ? *Mycetophila* was obtained as a pupa from fifth stage dung in the laboratory. Unlike the Sciarid pupa this was suspended in a diffuse cocoon of white threads. The family is of no importance in the succession.

F. 5. TIPULIDAE.

Two Eriopterine flies were obtained in July, 1941, from artificially-moistened fifth stage cow dung. According to Imms (1938) the larvae may occur in damp situations among grass, roots, decaying vegetation, or may be aquatic. No sign of them in the field was seen.

F. 6. STRATIOMYIDAE.

While the adults of this family are mostly flower feeders, the larvae occur in diverse habitata such as water, soil, and rotting wood (Imms, 1938). The larvae of *Myiochrysa* have been found in cow dung (Williston, 1908). *Actinia incisuralis*, Macq. is found near carrion (Fuller, 1934).

At Crawley, *Neocxaireta spinigera*, Wied. was seen to lay clutches of eggs on fresh cow dung in the laboratory in May and June, 1941. These hatched within three days, but the larvae failed to complete their development. Other larvae collected on 7th November, 1940, which probably belonged to this species, reached the pupal period by 10th April, 1941, but no adults emerged.

Stratiomyid larvae occur occasionally at Crawley in cow dung in the field, although more numerous in rotting vegetation. These larvae, in the course of their relatively long lives, must tolerate the change in condition of the dung from fresh to old and dry, whereas in other dung-breeding insects the larvae are generally restricted to the one stage or to stages which show no marked differences.

F. 7. DOLICHOPODIDAE.

A number of black predaceous flies, near *Asyndetus* sp., occur during autumn and winter on fresh cow dung, preying on the Borborids attracted to it.

F. 8. PHORIDAE.

Flies near *Chaetocnemistoptera* in Curran's Key to the North American genera (Curran, 1934) are frequently attracted to cow dung in the laboratory. The relationship of carrion to cow dung insects holds good as *Sciadocera rufomaculata*, White, and *Beckerina* sp. are members of the carrion association at Canberra (Fuller, 1934).

F. 9. SEPSIDAE.

These are characteristic excrement insects with a world-wide distribution. *Sepsis violacea*, Meigen, breeds almost exclusively in excrement, including that of man (Howard, 1912). There are 30 species of Sepsidae in Great Britain (Imms, 1938). In Denmark, numbers of *Sepsis* sp. emerged from cow, horse, and pig dung (Thomsen & Hammer, 1936). Sepsids are common in the tropics on dung of all kinds (Patton & Cragg, 1913). In Australia "the known species of the family occur in the adult stage on garbage, carrion, or vegetation, some being very abundant on flowers. The larvae feed in manure and carrion" (Malloch, 1925A).

At Crawley, Sepsids are the most characteristic flies on cow dung. Two species are present, viz., *Australosepsis fulvescens*, Mall., which appears to contain only males, and its black variety *atrata*, Mall., of which both males and females are known, and *Sepsis plebeia*, de Meij. Both species breed in cow dung in the field.

A. fulvescens is most numerous from November to May, and *S. plebeia* during most of the year except January and February. The latter species was collected at Katanning in August, 1941. Both are members of the carrion association at Canberra. A single specimen of *S. hirsuta*, de Meij., was bred from cow dung at Dog Swamp, Tuart Hill, W.A., in January, 1942.

The Sepsids appear on the fresh dung and remain until after the superficial skin has become a firm crust, spending the time in feeding and oviposition. While parading on the dung they generally pair off and indulge in remarkable antics. Each female carries a male, which applies its labella to her cervical membrane and engages its legs on her prothorax. They remain for hours thus, keeping up a ceaseless movement of legs and wings, yet the time of actual sexual contact is short.

Oviposition has been observed only in *Sepsis plebeia*. The female, still carrying the male, partly extrudes the egg several times before depositing it with a sudden thrust of the abdomen. Usually buried in the dung, the egg is occasionally merely dropped on the surface of the cake. Sepsids are frequently seen ovipositing in dung in which eggs of large Muscids have already hatched. This is probably due to the Sepsids remaining for a longer time on the dung, because it is their main food, than do the Muscids, in the diet of which it is only a subsidiary item.

Only one egg is usually laid in a particular spot. Constant returning of the female to the same place results in the formation of large clutches of eggs just below the surface with the interlacing respiratory processes (Pl. 1, Fig. 9) forming a white network which is often conspicuous on the surface. The eggs hatch in about 24 hours.

The larvae (Pl. 1, Fig. 10) are truly coprophagous, occurring mostly in second and third stage dung, occasionally in the first and very rarely in the fourth. The length of larval life is approximately 10 days.

Pupation normally occurs in the dung itself, usually in the peripheral layers, sometimes on the lower surface. The pupal period in September, 1941 (average temperature, 13.9° C.) was 23 days. The total life history from laying of the egg to emergence of the adult took 33 days in September and October (average temperature, 16.1° C.), 1941.

Because they occur in large numbers and not only consume but tunnel through the dung, the larvae assist greatly in changing its nature. They are parasitised at Crawley by an unidentified Alysid which emerges from the puparium. It is not an efficient parasite as infested stages are not common.

F. 10. BORBORIDAE.

Malloch (1925B) mentions the occurrence of larvae and adults of this cosmopolitan family on manure and earrion in New South Wales. Two species of *Leptocera* frequent earrion at Canberra (Fuller, 1934). In America, Howard (1912) reared *Limosina* (= *Leptoeera*) and *Sphaeroeera* from cow dung and human faeces. In India, *Borborus* is often infected with a herpetomonas as is *Sphaeroeera* in France (Patton & Cragg, 1913). Thomsen & Hammer (1936) bred Borborids in cow, calf, pig, and horse dung in Denmark. They were present in large numbers on pig, sheep, and cow dung at Katanning in August, 1941. At Crawley they are associated with earrion, rotting grass, cow, and horse dung.

Most of the small black flies around cow dung at Crawley are Borborids, species of *Leptoeera* with a few others belonging to other unidentified Acalyptrate families. The largest species of *Leptocera* has actually been reared from cow dung, though it is the least common in the field. The habits of the pregnant females of the smaller species leave little doubt that they also breed in this medium.

The Borborids are abundant on cow dung from May to October, with a diminution in the complementary period. They rapidly appear on the fresh dung. Unlike the Sepsids they can be found actually underneath the dung pad. The adults feed on the fresh dung, the pregnant females becoming remarkably distended. No information on the immature stages has been gleaned at Crawley.

F. 11. DROSOPHILIDAE.

Though the usual association of Drosophilids is with fermentable materials, some breed in cow dung. They are not common at Crawley in the field, being most numerous in July, August, and September, during which period their larvae may be found in second and third stage dungs. The Drosophilids found on cow dung at Crawley and cow and pig dung at Katanning trace to the genus *Cladochaeta* in Curran's Key to the North American Genera.

The larvae are eophagous and similar in habits to those of Sepsids. Pupation occurs in the drier parts of the dung, the pupal period lasting about three weeks.

F. 12. OTITIDAE.

Only two of the species of this family frequenting cow dung at Crawley, *Pogonortalis barbifera* Macq. and *Chrysomyza aenea*, Fab., have been identified. *P. barbifera* resembles the Sepsids in the fanning movements of the wings. That *C. aenea* breeds in cow dung on occasion was shown by examination of a sample of fourth stage cow dung from Armadale in March, 1941. This dung had fermented to the extent that steam rose off it and it felt warm to the touch, both unusual conditions. It contained a large number of puparia and nearly mature larvae of *C. aenea*, pupae of *Cercyon haemorrhoidalis*, one of *Leptaeinus soei*, three larvae of *Saprinus* sp., and a pupa of *Musca domestica*. Specimens in the collection of the Department of Agriculture, Perth, reared from larvae taken in silage waste at Boyanup appear to belong to *C. aenea*.

The larvae perform peculiar skipping evolutions when disturbed. The body is flexed ventrally to enable the mouth hooks (Pl. 1, Fig. 11) to grasp the terminal part of the body, probably the raised area round the anus. Then the longitudinal body muscles are strongly contracted. The mouth hooks suddenly release their hold, producing sufficient force to flip the

larvae up to a foot from its starting point. These acrobatics are similar to those performed by the larvae of *Piophila casei*, the so-called "Cheese Skippers." Continuous stimulation will cause a larva to repeat these movements until it can no longer lift itself from the ground.

Pupation occurs in the dung, the puparium being reddish-brown in colour. No exact figures of the length of life history are available. Larvae of unknown age collected on 3rd April, 1941, had all given rise to adult flies by 30th May, so that in some cases the life history requires more than 58 days, longer than that of dung-breeding Museids.

F. 13. CALLIPHORIDAE.

Sub-Family 1: CALLIPHORINAE.

Calliphora (Neopollenia) australis, Boisd., *Calliphora (Procockon) nociva*, Hardy, and *Lucilia cuprina*, Wied., all visit fresh cow dung in spring and autumn, though never in large numbers. Attracted by the odour, the adults suck up the liquid dung, often in large quantities, but no evidence of their breeding in cow dung at Crawley was obtained. Their association with it is thus of a casual nature and can have no effect on the succession.

Sub-Family 2: SARCOPHAGINAE.

In the period October-November, 1941, 10 specimens of *Sarcophaga (Parasarcophaga) depressa*, Desvoidy, were reared in cow dung from Crawley, and in January, 1942, 53 from dung obtained at Dog Swamp, W.A. The eggs are deposited in fresh dung, especially in strong-smelling cakes. In spite of their large size, 20 to 30 larvae per cake may occur. They generally leave the dung to pupate without displaying the same degree of restlessness prior to pupation displayed by the larvae of *Calliphora stygia*. The cakes which sheltered the larvae contained normal populations of other insects.

S. varia Walk. normally breeds in cow dung in New Zealand. Two species of *Sarcophaga* frequent carrion at Canberra (Fuller, 1934), while various species of the genus attack living sheep as secondary blowflies in the tropical and sub-tropical parts of Northern Australia (C.S.I.R., 1933).

F. 14. MUSCIDAE.

Sub-Family 1: FANNIINAE.

? *Fannia* sp.

One fly probably belonging to this genus was bred from cow dung in the laboratory at Crawley. The eggs were laid on 16th September, 1941, hatching about eight days later into "hairy" maggots. These remained on the surface of the dung without penetrating it until 20th October, when four pupated. The only fly which emerged at all did so on 2nd November.

In the field, eggs are common and larvae have been seen on two occasions, having actually penetrated into third stage dung but no adults have been bred out.

Sub-Family 2: MUSCINAE.

Musca domestica, Linn.

Cow dung has very little attraction for the ovipositing female and this fly has not been bred out of it at Crawley. A single puparium, which subsequently gave rise to a female *Musca domestica*, was found in cow dung from Armadale which was of an unusual type, as described in the section on the Otitidae, though it contained the usual insect population. The presence of the puparium is remarkable, because the dung contained no admixture of any

other material. Where *M. domestica* is found breeding in cow dung, the material is generally mixed with straw or some such substance (Austen, 1928. Results quoted by Thomsen & Hammer).

***Musca vetustissima*, Walker.**

This is the common bush fly which annoys workers in the open because of its habit of clustering on the face and attacking the eyes. Its activities have earned it the title of the "Queensland cattle fly" and it also pesters horses. It is of some economic importance because it transmits *Habronema muscae*, a Nematode parasite in the stomach of the horse and another undetermined species of *Habronema* which causes habronemiasis conjunctivitis of horses (Johnston & Bancroft, 1920). It is probably capable of setting up Anthrax infection under some circumstances (Cleland, 1913). The life history has been described by Johnston & Bancroft (1919), the breeding medium being either horse or cow dung. The total period of development from the egg to the adult in the Eidsvald district of Queensland was found to be 10 to 14 days in November.

At Crawley the flies are numerous on fresh dungs although only six specimens have actually been reared from dung in May, 1941. In January, 1942, large numbers were reared from cow dung from Dog Swamp, Tuart Hill—W.A., which also contained maggots of *Sarcophaga (Parasarcophaga) depressa*, Desvoidy.

Sub-Family 3 : ANTHOMYIINAE.

***Hylemyia deceptiva*, Mall.**

A single specimen of this species or near to it was bred out from cow dung in September, 1941. *H. deceptiva* is recorded on carrion at Canberra (Fuller, 1934). Another undetermined species of *Hylemyia* was bred from second stage cow dung in June, 1941.

H. variata Fallen and *H. strigosa* Fallen, which occur in Ayrshire and Arran in West Scotland are ovoviparous flies. Whether this is the case with the local species is as yet unknown.

Sub-Family 4 : PHAONIINAE.

***Rhynchosomydaea (Hardyia) carinata*, Stein.**

Flies near this species are the commonest of the large Muscids frequenting cow dung at Crawley. The adults, which feed on fresh dung, occur during the period May to November, while specimens have been bred out from cow dung in the period March to November. The species is present at Katanning.

Eggs are laid singly with the anterior ends projecting in fresh dung. About 14 larvae is the maximum number which mature in each cake. They occur in first to third stage dung, the larvae period being about 14 days. The larvae are coprophagous.

Pupation occurs in the dung, usually in a hollowed cavity on the lower or near the upper surface. Sometimes, after heavy rain, puparia may be found on top of cakes in shaded situations. The pupal stage lasts about three weeks. The total cycle from egg to emergence of the adult took 34 days in September (average temperature 13.9° C.) and October (16.1° C.), 1941.

HELINA.

This genus is wide-spread in Australia (Malloch, 1925C) and is represented at Crawley by the following species:—

Helina coerulescens, Stein.

Though common on fresh dung at Crawley during the same period, this metallic fly has not yet been reared from cow dung. It is similar in habits to *R. carinata*.

Helina hypopleuralis, Mall.

Four specimens bred from cow dung at Crawley in September and November, 1941, belong to this species or to one near it.

Helina regina, Mall.

One specimen near this species was reared from cow dung at Crawley.

Muscina stabulans, Meig.

This wide-spread species has a variety of breeding media. Howard (1912), in America, lists as food for its larvae, decaying animal matter, cow dung, fungi, caterpillars, larval bees, dead pupae, decaying plant materials, and human excreta. Fuller (1934) notes its association with carrion. In Denmark it was reared from pig, cow, and calf dung (Thomsen & Hammer, 1936). The flies have been reared from rotting potatoes and also from earrion in Australia (Hardy, 1938), whereas Muirhead Thomson (1937) stated that he had never seen nor had been able to induce oviposition by *M. stabulans* on earrion.

Only one specimen has been reared from cow dung at Crawley.

Order 7—HYMENOPTERA.

F. 1. ALYSIIDAE.

An undetermined species of *Alysiiid* is associated with cow dung at Crawley, most numerous during the period February to November. In spite of their delicate build they sometimes penetrate deeply into the interior of cakes, presumably to parasitise Sepsid and Drosophilid larvae, since puparia so infested are occasionally found. Females are more numerous than males.

An Alysiid, *Alysia manducator* Pantzer, has been introduced into Australia as a parasite of sheep blowflies, but it has failed to establish itself (C.S.I.R. 1933).

F. 2. FIGITIDAE.

Small wasps belonging to this family are encountered throughout the year in and on first stage dungs. As no material parasitised by them was obtained, their hosts are not known. This is also true of a number of other wasps belonging to various families, which were not identified because nothing is known of their habits.

F. 3. FORMICIDAE.

On fresh dungs, small ants are usually present as predators attacking adult Borborids and Sepsids. In due course they carry off immature stages of beetles and flies. They are most active during the summer, at which time they appear to influence the population considerably. Nevertheless, in August, 1941, many of the second and third stage cow dungs were packed with pupae which ants were removing.

Small amber-coloured ants frequently form colonies under dung cakes of all stages in spite of the conclusions of Forel and Wheeler that they will not do so except to seek shelter from the sun or moisture, both of which are amply available at Crawley under stones or vegetation. Again, the odour does not prevent ants from penetrating into even fresh dung, although Wheeler (1926) refers to their dislike of bad odours such as those of carrion and mammalian faeces.

Order 8—LEPIDOPTERA.

Three larvae collected on the 5th September, 1941, on top of late fifth stage cow dung about three months old, kept in the laboratory. They were apparently feeding on the dry and crumbling fibres of the cake. The three larvae pupated five days later. After an additional 23 days, one gave rise to a small Oecophorid moth. The larvae have not been seen in the field.

The association of these larvae with cow dung is of the same order as *Monopsis rusticella*, Hubn., a Tineid moth breeding in the wool of an old sheep carcase reported by Fuller (1934), being divorced in time and space from those insects which form the succession proper.

8. OTHER ANIMALS ASSOCIATED WITH COW DUNG AT CRAWLEY.

A. Other ARTHROPODA.

1. ACARINA.

A large number of mites belonging to the Parasitidae are found in cow dung at Crawley. They breed in the dung and frequent all stages except the final part of the fifth. A considerable variation in the mite population of individual cakes is noticeable.

In the field both flies and beetles are found carrying numbers of mites which may merely hang by their claws or adhere by a secretion. *Proctophanes sculptus*, Hope, is especially liable to act as a carrier, as its clumsy build and slowness of movement prevent it from dislodging its passengers.

Under laboratory conditions, where dung is kept covered, mites multiply to a remarkable extent. Though mites have not been seen, except in a few doubtful cases, to molest them, immature stages of flies and beetles diminish in number in dungs with a high Acarine population density.

At Katanning in August, 1941, no Parasitids were seen on cow dung in the town itself and very few in material five miles away, a strong contrast to the large numbers present at Crawley in the same month.

2. CRUSTACEA.

Fourth and fairly moist fifth stage cow dung often shelters associations of *Porcellio* sp. at Crawley. They offer little or no competition to such immature stages of Hydrophilids or Scarabaeids as are present.

B. NEMATODA.

If kept in closed vessels, cow dung is an ideal nidus for these minute worms. In the field they are not noticeable as a rule until pupae of *Cercyon* begin to appear in fourth stage dung cakes. A number of these have bunches of Nematodes hanging from the appendages or on the ventral body surface, often numerous enough to force the wings of the pupa into an unnatural posi-

tion almost at right angles to the long axis of the body. Since most of the pupae in this condition are able to transform normally, it seems that the Nematodes are free living forms attracted to them by the moisture given off.

Adult Cercyons, when kept in closed vessels with cow dung, often contain Nematodes in the posterior part of the alimentary canal and genital tract as well as on the moist body surfaces. There is no reason to believe that the presence inside the body is due to anything more than the tendency to migrate into any aperture.

C. ANELIDA.

Fresh cow dung attracts earthworms which will consume large quantities if it is applied to garden beds containing them. They are also of frequent occurrence in heaps of fourth stage cow dung which has retained moisture. Nothing definite is known of the degree of competition they offer to the true dung insects.

9. FEATURES OF THE SUCCESSION IN COW DUNG.

Having referred to various aspects of the biology of the insects concerned, it is now possible to draw up a scheme showing the features of the succession, defined according to the stage through which the cow dung passes, as set out in section 4.

First Stage.

This is characterised by the activities of dung insects on the surface of the fresh dung. The Sepsids, Borborids, Calliphorids, Otitids, and Muscids appear to feed on the liquid dung in such a haphazard manner that the order varies for practically every dung.

The dung beetles are also prompt in arrival and again no particular order can be defined. The Staphylinids, Hydrophilids, Histerids (in season) and Aphodiines, except *A. ambiguus*, all commence to penetrate either through natural crevices on both surfaces or by creating apertures in the superficial skin.

Toward the end of the first stage, the number of flies diminishes. The Calliphorids leave first, the only attraction for them being the soft dung now covered with a firm skin, and then the large dung-breeding Muscids after oviposition. The Sepsids and Borborids remain longer, and the former may be seen ovipositing over some days. The predatory Dolichopodids and *Creophilus erythrocephalus* also leave when the numbers of their prey diminishes.

Second Stage.

The surface layers of the cake become penetrated by the dung beetles. Sepsids and Borborids are still present. Mites and Collembola appear early in this or late in the first stage. Although the eggs of Muscids and Sepsids have hatched, the small size of the larvae renders them inconspicuous. Adult Psychodids are to be found ovipositing on cakes in the shade.

Third Stage.

The dung is extensively penetrated by beetles. In many cases an unpenetrated core near the lower surface is left but many cakes are completely riddled. The activities of Cercyons and *Aphodius lividus*, by admitting air into the dung, give it its characteristic black colour. The latter part of this period is primarily one of immature stages. The population of Sepsid, Drosophilid, and Psychodid larvae becomes very high. Cercyon and even occasional Scarab larvae appear towards its end, as the emigration of adult beetles begins.

Fourth Stage.

Except for occasional specimens, usually Staphylinids, the population of adult beetles is low apart from *Aphodius ambiguus*. Larvae and pupae of Staphylinids, Cercyons, eggs and larvae of Aphodiines are present in the peripheral regions. The Psychodids have disappeared. Larvae of *Sciara* sp. hatch out in this stage. Most of the Brachycerous Dipteran larvae have pupated. Mites and Collembola still remain in some numbers.

Fifth Stage.

The population is essentially similar to that of the previous stage, progressively diminishing in size as the dung becomes drier. Ultimately, in the final stages, the Aphodiine larvae have undergone metamorphosis and vanished. The dung no longer contains insects and serves only to shelter a few, the presence of which under it is purely fortuitous.

The following minor successions compose the main one:—

1. The succession of visitors to inhabitants, which arises out of the alteration of the dung, due more to oxidation and other chemical changes at its surface than to any activities of the insects.
2. The succession among the adult Coleoptera. The majority of the early invaders move out in the third stage and are succeeded by *Aphodius ambiguus* in the early fourth, which is replaced in turn only by the casual shelterers of the fifth. The cause of the emigration in the third stage is not always clear. High population densities may cause a rapid change in the quality of the dung which becomes unsuitable for the adults and consequently they leave. There are, however, many instances in which the insects abandon the dung while it still offers abundant food and space. Competition may cause the emigration of surplus individuals. This would lessen its intensity and there would be no reason for any more to leave. The exodus of all beetles from a dung of this type may be due to the tendencies found among gregarious insects to keep close together and to imitate each other's movements, which are believed to be responsible for such phenomena as the swarming of locusts (Uvarov, 1928). It is an open question whether the gregariousness of dung beetles is real or due to purely chance associations resulting from large numbers of individuals responding to the same stimulus. In any case, the migration of dung beetles is a gradual process not comparable with any form of swarming.
3. The succession among the larval stages. Larvae appear in cow dung in the following order:—
 - 1st Stage—Sepsid, Drosophilid, Borborid (?), Muscid.
 - 2nd Stage—Psychodid.
 - 3rd Stage—Hydrophilid, Staphylinid.
 - 4th Stage—Aphodiine, Sciariid.

In carrion the succession is assisted by the predaceous activities of the secondary blowfly maggots which actually attack or drive off those of the primaries. In the cow dung population none of the larvae of importance in the succession are predatory on the others except those of Staphylinids, which do not appear in sufficient numbers to influence the total. Aphodiine larvae succeed those of *Cercyon* only because their physiology is better adapted to existence in fourth stage dung. The effect of competition is therefore to regulate the number of individuals found in any stage and plays little part in replacing one species by another.

Chapman (1931) divides animal successions into passive and active according to the part played by the animals concerned. Though less so than that in carrion, the succession in cow dung is of the active type since the insects do affect their environment. Volume for volume cow dung supports a smaller population than carrion. This is due to the less powerful odour which is the primary attracting stimulus, the less nutritious nature of the dung itself, and in the case of flies the comparatively short time during which it is a suitable medium for oviposition owing to the early formation of a more or less impervious crust. All these factors result in a less well-defined succession than occurs in carrion.

As has been indicated previously, there is a correlation between the type of insect in carrion and that in dung, many species being common to both habitats. Nevertheless, each substance has its own characteristic insects physiologically adapted to it with only a casual association with the other. Blowflies visit cow dung but their life history is bound up with carrion. In the same way, Cercyons are sometimes found on carrion yet they are characteristic cow dung insects.

Both in carrion and cow dung are insects which either have a wide distribution themselves, *e.g.*, *Aphodius lividus*, *Cercyon haemorrhoidalis*, or have closely allied species in other parts of the world, *e.g.*, *Sepsis plebeia*. This is to be expected, as neither carrion nor faecal matter is subject to geographical variation.

10. THE ECONOMIC IMPORTANCE OF INSECTS FOUND IN COW DUNG.

The primary sheep blowflies *Calliphora australis* Boisd, *C. nociva* Hardy, and *Lucilia cuprina* Wied., have only a casual association with various species of *Sarcophaga*, are secondary sheep blowflies, and some of these breed in cow dung, though the importance of this material to the flies as a breeding substance is not known. *Musca domestica* Linn. prefers other breeding nidi, and no evidence has been seen that *Stomoxys calcitrans* Linn., which occurs in numbers in Perth, ever frequents dung at Crawley. Research in various parts of the world has shown that cow dung is among the least favoured of the breeding media of this fly.

Musca vetustissima Walker is a common pest in Perth on man and cattle. Cow dung is an important source of the fly here, especially that dropped in swampy situations. *Rhynchosydaea carinata* Stein and the species of *Helina* associated with cow dung at Crawley are not domestic insects, nor have they, as far as is known, any habits rendering them objectionable to man. *Muscina stabulans* Fallen is not abundant at Crawley. In any event, cow dung is only one of a large number of breeding materials utilised by this fly.

In South Australia and Tasmania, two Aphodiines, which normally feed on dung, have come under notice because their larvae have been found damaging pastures and lawns (Swan, 1934; Evans, 1941). These are *Aphodius howitti*, Hope, and *A. tasmaniæ*, Hope, neither of which has been collected at Crawley. No complaints have been received by the Department of Agriculture against any local species in this connection.

When L. J. Newman, in 1929, succeeded in rearing *Lyperosia exigua* de Meij., the Buffalo fly on cow dung under midwinter conditions in Perth, without the application of artificial heat, it was feared that this pest might be introduced in the dairying regions in the southern part of the State. Precautions against this possibility in the form of spraying cattle before they left North-West ports were introduced (Toop, 1931). The fly has not been reported in the South-West, nor has any sign of it been seen at Crawley.

The typical dung insects—Sepsids, Hydrophilids, Aphodiines, etc., all play their part as scavengers in getting rid of waste material, but the actual evaluation of the economic importance of this part is practically impossible.

ACKNOWLEDGMENTS.

The writer wishes to express his indebtedness and gratitude to the following, while absolving them from any responsibility regarding statements of opinion by the writer:—Professor G. E. Nicholls for general help and guidance; Dr. A. J. Nicholson for suggesting the nature of the problem studied; Mr. K. C. McKeown and officials of the Australian Museum, Sydney, for the identification of the Coleoptera; Mr. G. H. Hardy for the identification of most of the Diptera; Mr. J. H. Perkins for the identification of Sepsidae and Borboridae; the Officers of the Entomological Branch of the W.A. Department of Agriculture for their co-operation; Dr. G. A. Currie and Mr. K. R. Norris for advice on various aspects of the problem.

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EXPLANATION OF PLATE 1.

Fig. 1.—*Cercyon haemorrhoidalis* Fab. Variety 1.
Ventral view of Adult.

Fig. 2.—*Cercyon haemorrhoidalis* Fab.
Dorsal view of Mature Larva.

Fig. 3.—*Leptacinus socius* Fauv.
Lateral view of Pupa.

Fig. 4.—*Aphodius lividus* Oliv.
Ventral view of Pupa.

Fig. 5.—*Psychoda* sp.
Ventral view of Larva.

Fig. 6.—*Sciara* sp.
Partially dorsal view of Larva.

Fig. 7.—? *Rhegmoclema* sp.
Lateral view of Larva.

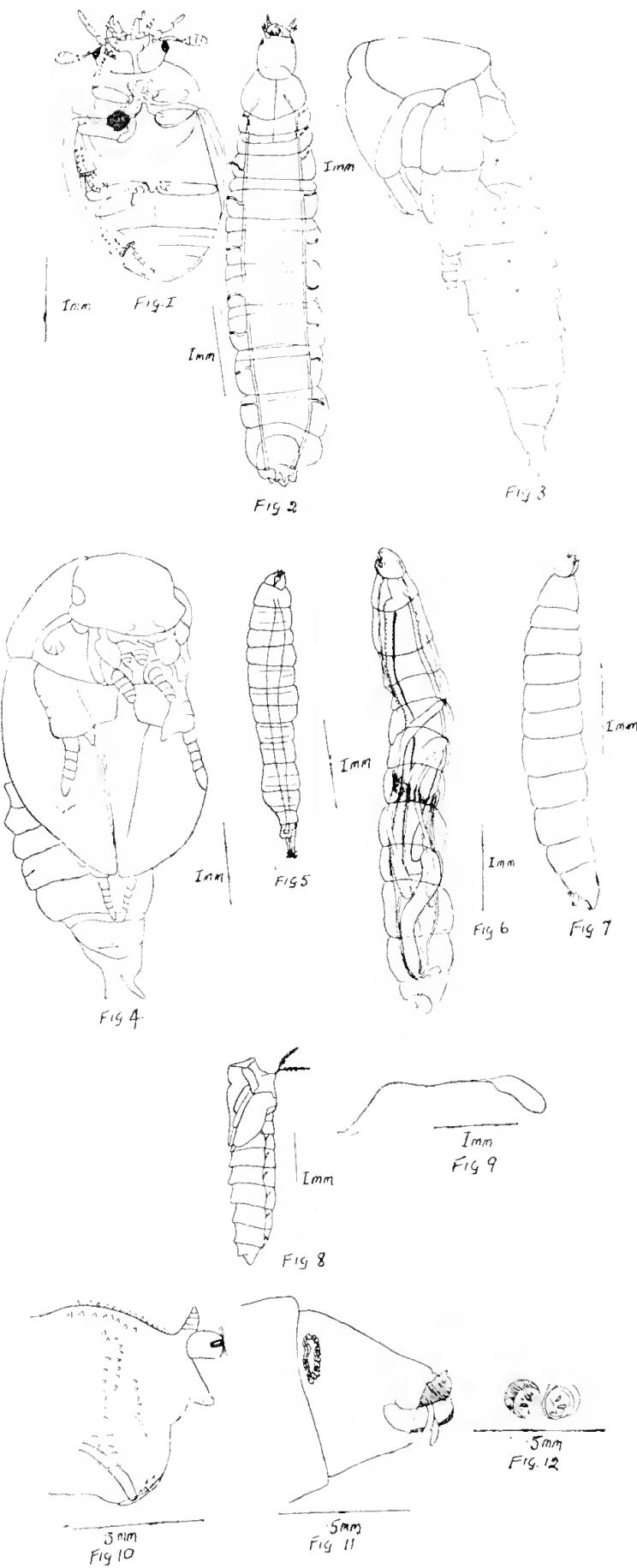
Fig. 8.—? *Rhegmoclema* sp.
Lateral view of Pupa extracted from skin of last larval instar.

Fig. 9.—*Sepsis plebeia*, de Meij.
Egg.

Fig. 10.—*Sepsis plebeia*, de Meij.
Lateral view of terminal segments of Larva.

Fig. 11.—*Chrysomyza aenea* Fab.
Lateral view of anterior region of nearly mature Maggot.

Fig. 12.—*Rhynchosomydaea* (Hardyia) *carinata* Stein or near.
Posterior spiracles of second Larva.



13.—THE ESSENTIAL OILS OF THE WESTERN AUSTRALIAN EUCALYPTS.

PART VII.

THE OIL OF *EUCALYPTUS ERYTHRONEEMA*, TURCZ.

BY E. M. WATSON, Ph. D.

Read 9th June, 1942; published 28th March, 1944.

Eucalyptus erythronema Turez. has been recorded as occurring along the Eastern Railway from Tammin to Southern Cross. North of Tammin, it is known at Wyalkatchem and Cowcowing and, farther west and north-west, at Wongan Hills and Ballidu. It also occurs south of the railway, and the material used in this investigation was collected some 10 miles south-east of Merredin.

It is a small tree, 12 to 18 feet high, or a mallee with a bulbous stock and several erect stems. It grows in clay soil, usually associated with *E. salubris* and *E. salmonophloia*, either in the mallee association fringing the woodland or in the woodland. The leaves are lanceolate, narrow lanceolate, or falcate in shape, and are from two inches to four inches long. The colour is a dark and usually lustrous green, the venation of the cineole type and the submarginal vein is removed from the edge. The lamina is copiously dotted with oil glands. The bark is covered with a fine white talc-like powder which easily rubs off, leaving, in the older parts, a pinkish bark. Because of this white powder on the stem and branches, it is commonly called the "white mallee." The wood is dark brown in colour, is very hard and susceptible to termite attack, which, however, is confined to the heart wood.

The material used was collected by Mr. G. E. Brockway of the Forests Department, towards the end of August, 1941. It was obtained from mallees on Avon Location 20751, about 10 miles south-east of Merredin, and its identity was confirmed by Mr. C. A. Gardner, Government Botanist.

The air-dried terminal branches were steam distilled, the oil coming over very rapidly. It was pale yellow in colour and had an irritating odour; the yield averaged from 2.5 to 2.6 per cent. by weight. The physical constants of the oil are those of a typical cineole oil, and its solubility in alcohol shows a low proportion of terpenes. The crude oil itself contains over 70 per cent. of cineole, whilst the rectified oil contains 80 per cent. of cineole. Free acids and esters are present in only small amount, but alcohols, the greater part of which is geraniol, make up more than 13 per cent. of the oil. Both low and high boiling aldehydes are present, but in no great quantity.

The rectified oil, boiling between 164° and 185°, is a very high grade medicinal oil. It makes up over 80 per cent. of the oil, contains, as already stated, 80 per cent. of cineole, and complies with all the requirements of the British Pharmacopoeia for eucalyptus oil. It is colourless and has a very pleasant, non-irritating, camphoraceous odour.

Although clearing for farming has probably removed appreciable quantities of this eucalypt, its commercial exploitation should still be possible. Cultivation should also be economically sound on account of the good yield of high grade oil obtainable from it.

EXPERIMENTAL.

The oil distilled completely in three hours and the undried oil had the following physical properties at 20° C. :—Specific gravity, 0.923; refractive index, 1.466; specific rotation, -0.22°. It was soluble in two volumes of 70 per cent. alcohol. Its acid value was 0.6; its saponification values were:—Cold, 1.9; hot, 3.2, corresponding respectively to 0.67 per cent. of geranyl acetate and 1.1 per cent. of total esters calculated as $C_{12}H_{20}O_2$. The saponification values of the acetylated oil were:—Cold, 43.8; hot, 52.5, corresponding respectively to 11.5 per cent. of alcohols calculated as geraniol and 13.5 per cent. of total alcohols calculated as $C_{10}H_{18}O$. The aldehyde content of the oil was 0.12 millimole per gram of oil, equivalent to 1.8 per cent. of aldehydes calculated as $C_{10}H_{14}O$. The cineole content of the dried oil was 70.9 per cent. The usual colour reactions for aromadendrene were obtained but the oil gave no reactions for pinene or phellandrene.

The oil was redistilled and the following fractions were separated:—

Fraction.	Boiling Range.	Amount per cent.	Specific Gravity.	Refractive Index.	Specific Rotation.
1	Up to 160°	2.8	0.897	1.442	+14.1°
2	160°—167°	11.75	0.901	1.462	+16.1°
3	167°—169°	11.25	0.912	1.461	+ 6.5°
4	169°—176°	57.4	0.920	1.461	+ 1.2°

The residue was further fractionated under reduced pressure and the following fractions separated:—

5	80°—90°/27 mms.	2.2	0.959	1.480	-23.8°
6	90°—110°/26 mms.	6.0	0.967	1.494	-36.2°
7	110°—120°/25 mms.	1.7	0.965	1.496	-19.7°

As the initial boiling commenced, the formation of white insoluble material was noted and from the final residue 2.3 per cent. of white amorphous solid was separated by addition of ether, followed by filtration.

Fraction 1 contained some water which was separated. This contained both aldehydes and free acids, the latter including butyric, probably valeric, and either or both formic and acetic acids. From this aqueous portion a small quantity of colourless crystals separated. These crystals are neutral, soluble in alcohol, may be recrystallised from water, give no colour with ferric chloride, and melt at 145°. From the oily part of this fraction no reactions for pinene were obtained.

Fraction 2 contained 59.3 per cent. of cineole, was colourless and pleasant-smelling, and had cold and hot saponification values of 5.9 and 8.2 respectively.

Fraction 3 was similar and contained 76.5 per cent. of cineole, whilst Fraction 4 contained no less than 88.8 per cent. of cineole. The saponification values of these two fractions were respectively 2.2 and 2.9 (cold) and 3.1 and 3.6 (hot). No crystalline nitrosoite was obtained from Fractions 2, 3, and 4.

Fraction 5 was colourless and contained the greater part of the esters, having cold and hot saponification values of 56.6 and 63.9 respectively, corresponding to 20.8 and 22.4 per cent. of esters, calculated as $C_{12}H_{20}O_2$. This fraction, as well as fractions 6 and 7, contained a small amount of aldehyde.

Fractions 6 and 7 had cold saponification values of 19.1 and 15.8 respectively and hot saponification values of 22.5 and 20.3.

Fraction 7 (which was pale yellow in colour) and the final residue both gave a purple colouration with ferric chloride.

Distillation of 150 grams of the oil gave 123 grams (82 per cent.) of oil, distilling between 164° and 185°. This oil contained 80 per cent. of cineole and had the following physical properties at 20°:—Specific gravity, 0.918; refractive index, 1.461; specific rotation, +2.76°. It was soluble in two volumes of 70 per cent. alcohol. The requirements of the British Pharmacopoeia for eucalyptus oil are:—Cineole, not less than 70 per cent.; specific gravity (15.5°/15.5°), 0.910 to 0.930; refractive index (20°), 1.458 to 1.470; optical rotation, —5° to +5°; soluble in five volumes of 70 per cent. alcohol. The oil gave no reaction for phellandrene and, when tested for aldehydes by the Pharmacopoeial method, required 0.65 ml. of 0.5N alcoholic caustic alkali (B.P. figure, not more than 2 ml.).

The author is indebted to Mr. G. E. Brockway for the collection, and to Mr. C. A. Gardner for the identification of the material.

Perth Technical College.

GENERAL INDEX.

	Page
Amphibolites, of Toodyay district	104, 111, 119
Amphibolites, analyses	105
Andalusite, Toodyay district	101, 129
Arthur River	13
<i>Aulosteges</i>	11, 12, 32, 39, 40
<i>Aulosteges baracoodensis</i>	7, 29, 32
<i>Aulosteges medlicottianus</i>	32, 35, 36
<i>Aulosteges spinosus</i>	36
<i>Aulosteges tibeticus</i>	32, 35
<i>Aulosteges wangenheimi</i>	8, 32, 33, 34
<i>Aulosteges wolfcampensis</i>	32
<i>Aronia</i>	30
Ballythanna Hill	27
Balmaningarra	54
Barrabidby	54
Barragooda Pool	13
Booker, F.	40
<i>Branxtonia</i>	38, 40, 41
<i>Branxtonia typica</i>	40
Broili, F.	16, 17, 18, 20, 23, 26
Bryozoa from the Upper Palaeozoic of Western Australia, A Revision of some previously described species of	187
Bryozoa from the Wandagee and Nooncanbah Series (Permian) of Western Australia	165
Bullsbrook, fossil plants from	201
<i>Calceola</i>	9
Calc-silicate rocks, of Toodyay district	94, 118
Callytharra Springs	13, 21, 30, 43
<i>Cancrinella</i>	32
Capertree, N.S.W.	42
<i>Centropages australiensis</i> , sp. nov.	209
Chao, Y. T.	16, 17, 20, 23, 25
Chapman, F.	13, 21, 22, 25
Chidlows	79
<i>Chonetella</i>	10
<i>Chonetes</i>	9, 12
Chonetinae	12
<i>Chonopectus</i>	10, 11, 12, 53
Christmas Creek Homestead	50
Chrome-muscovite, in Toodyay quartzites	91
<i>Cladophlebis australis</i>	201, 203
Climate of Western Australia	xxx.
<i>Clothoda nobilis</i>	140
Cockburn Sound, Pelagic copepods from	209
Condra, G. E.	8, 11, 40, 53
<i>Coniopterus hymenophylloides</i>	203
<i>Conoclypus</i> in North-West Australia	75
<i>Conoclypus westraliensis</i> , sp. nov.	75
Coolkilya Pool	27, 47
Cooper, G. A.	4, 13
Copepods, Marine from Western Australia	209
Copiapite	79
Cordierite anthophyllite rocks	118
Cow Dung, Insect population associated with at Crawley	219
Crawley, Insect population associated with cow dung at	219

	Page
Cretaceous, Lower, plants ...	201
Cummingtonite, in schist, Toodyay district	100
Davidson, T. ...	30, 31, 45
<i>Daviesella</i> ...	... 10, 12
<i>Dictyoclostus</i> ...	... 9, 12
<i>Dictyoclostus callytharrensis</i>, sp. nov.	4, 13, 19
<i>Dictyoclostus callytharrensis var. wadei</i> ...	... 16, 19
<i>Dictyoclostus gratiosus</i> ...	17
<i>Dictyoclostus indicus</i> ...	4
<i>Dictyoclostus semireticulatus</i> ...	29
<i>Dictyoclostus spiralis</i> ...	18
Diener, C. ...	11, 18, 20, 21, 23
Dolerite, quartz of Toodyay district	125
Dolerite, quartz, analysis ...	127
Douglas, J. A. ...	23
Dun, W. S. ...	... 21, 27
Dunbar, C. O. ...	8, 11, 40, 53
Dung, Insects associated with cow ...	... 219
Echinoidea ...	75
Eighty-mile beach, Ecological notes on the vegetation of	157
<i>Elatocladus</i> ...	201
<i>Elatocladus plana</i> ...	204
Embioptera of Western Australia, Revision of ...	139
<i>Eragrostis epipoda</i> ...	155
Etheridge, Jr. R. ...	13, 21, 22, 23, 27, 32, 39, 40, 42, 43, 45, 46, 47, 52, 54, 56
<i>Etheridgina</i> ...	... 10, 40, 52
<i>Etheridgina muirwoodae</i>, sp. nov.	54
Essential Oils of the Western Australian Eucalypts, Part VII. ...	247
<i>Eucalyptus erythronema</i> , oil of ...	247
Eulyrites, rocks related to ...	113, 115
<i>Fenestrellina affluensa</i> ...	188
<i>Fenestrellina cacuminatis</i>, sp. nov.	171
<i>Fenestrellina columnaris</i> , sp. nov. ...	170
<i>Fenestrellina disjecta</i> , sp. nov. ...	168
<i>Fenestrellina horologia</i> ...	167, 189
<i>Fenestrellina lennardi</i> , sp. nov. ...	171
<i>Fenestrellina ruidacarinata</i> , sp. nov. ...	169
<i>Fenestrellina valentis</i> , sp. nov. ...	169
Fibroferrite and Copiapite from Yetar Spring, near Chidlow ...	79
Foord, A. H. ...	... 22, 47
Fossil Cliff ...	9, 13, 24, 27, 43, 46, 51, 52
Fredericks, G. ...	2, 5, 29, 35
Gascoyne River ...	22
Gedrite, in schist, Toodyay district	100
<i>Gigantella</i> ...	12
Gingin, fossil plants from ...	201-7
Girty, H. ...	32
Glass Mts., Texas ...	8
Glanert, L. ...	13, 21, 22, 27
Gnarrea Pool ...	24
Gneiss, granitic, analyses ...	110, 123
Gneiss, granitic, of Toodyay district ...	107, 114
Gold, in Toodyay district ...	129
Granite, and related rocks of Toodyay district ...	124
Gray, J. E. ...	9
Greger, D. K. ...	53
Grossularite, Toodyay ...	95
Grunerite, Toodyay ...	117

	Page
Hamlet, B.	17, 18
Helmersen, G.	32
<i>Heteralosia</i>	12, 40, 41
<i>Heteralosia slocomi</i>	41
Hill, C.	47, 50
Hornblende schist, Toodyay district	104, 111
Hornblende schist, analyses	105
Hosking, L. V.	13, 15, 22, 27, 30, 36, 37
 Insect population associated with Cow Dung at Crawley, W.A., a consideration of	219
<i>Isoetes</i>	201
<i>Isoetes Boryana</i>	202
<i>Isoetes Engelmanni</i>	202
<i>Isoetites</i>	201
<i>Isoetites Chaffati</i>	202
<i>Isoetites elegans</i> , sp. nov.	202
<i>Isoetites horridus</i>	202
<i>Isoetites serratus</i>	202
 Jack, L. R.	21, 27, 42, 43
Jimba Jimba Station	13, 42, 47
Jipperding Series, at Toodyay, petrology of	88
Jurassic plants from Gingin	201-7
 King, R. E.	8
King, W.	9, 37, 45
Koninek, L. de	21, 42
Kozlowski, R.	7, 20, 23, 54
<i>Krotovia</i>	29
<i>Krotovia micracantha</i>	30
<i>Krotovia senticosa</i>	30
<i>Krotovia spinulosa</i>	30
 <i>Lepidocyclina</i>	76
<i>Leptalosia</i>	12, 40, 53, 54
Le Vene, C.	29
Licharew, B.	11, 12, 34, 35, 39
<i>Linoprotodus</i>	7, 20
<i>Linoprotodus cancriniformis</i>	23
<i>Linoprotodus cancriniformis</i> var. <i>lyoni</i>	24
<i>Linoprotodus cora</i>	20
<i>Linoprotodus cora</i> var. <i>foordi</i>	22
Liuilugui	25
<i>Lyropora erkosoides</i>	191
 <i>Machairopus cockburni</i> , sp. nov.	210
<i>Marginifera</i>	18
Marine Copepods from Western Australia, Series II.	209
Martin, W.	13
<i>Metoligotoma</i>	141
Middalya Station	13
<i>Minilya</i> , gen. nov.	172
<i>Minilya duplaris</i> , sp. nov.	173
<i>Minilya princeps</i> , sp. nov.	174
Minilya River	17, 24, 31, 47, 54
Morris, J.	27
Mount Abbott	47
Mount Cedric	25, 26
Mount Dromedary	27
Mount Hardman	25
Mount Marmion	4, 27, 54

	Page
Mount Nicholson ...	16
Mount Wellington ...	27
Muir-Wood, H. ...	6, 7, 8, 12, 31
 Netschajew, A. ...	34
<i>Nilssonia</i> ...	201
Nooncanbali ...	47
Nooncanbah Series (Permian) of Western Australia, Bryozoa from the Wandagee and	165
North-West Basin ...	9
<i>Notoligotoma</i> ...	144
<i>Notoligotoma hardyi</i> ...	144
Notoligotomidae ...	144
 Oehlert, D. P. ...	52, 53, 54
Oil of <i>Eucalyptus erythronema</i> ...	247
<i>Oligotoma</i> ...	141
<i>Oligotoma approximans</i> ...	142
<i>Oligotoma glauerti</i> ...	141
<i>Oligotoma gurneyi</i> ...	143
<i>Oligotoma gurneyi spinulosa</i> ...	143
<i>Oligotoma tillyardi</i> ...	142
Oligotomatidae ...	141
Orbigny, A. d' ...	20
<i>Orthis</i> ...	9
Orthotetinae ...	3
 Paeckelmann, W. ...	20, 30
<i>Pecten</i> ...	3
Pelagic Copepods from Cockburn Sound ...	209
<i>Phyllopterus</i> ...	201
Polypora fovea , sp. nov. ...	175
Polypora multiporifera , sp. nov. ...	177
Polypora reticulata , sp. nov. ...	17
Polypora , sp. nov. indet. ...	178
<i>Polypora woodsi</i> ...	177
Prendergast, K. L. ...	1, 23, 24, 25, 26, 27, 28, 47
<i>Proboscidella</i> ...	45
<i>Productella</i> ...	12, 54
Productellinae ...	11
<i>Productina</i> ...	12
Productinae ...	2, 8, 9, 12
<i>Productorthis</i> ...	13
<i>Productus complectens</i> ...	52
<i>Productus cora</i> ...	20
<i>Productus corrugatus</i> ...	21
<i>Productus latirostris</i> ...	38
<i>Productus lineatus</i> ...	21
<i>Productus neffedieri</i> ...	21
<i>Productus oratus</i> ...	21
<i>Productus prattenianus</i> ...	21
<i>Productus semireticulatus</i> (see also <i>Dictyostostus</i>) ...	13, 16
<i>Protembia</i> ...	139
<i>Ptilophyllum pecten</i> ...	204
<i>Pustula</i> ...	29
 Quartzite Pre-Cambrian, of Toodyay district ...	88
 Raggatt, H.G. ...	29
<i>Ramipora ambrosoides</i> ...	193
Reed, F. R. C. ...	16, 26, 45
Refractories, sillimanite and andalusite ...	129
Richthofeniidae ...	11
Rothpletz, A. ...	17, 26

	Page
Rowley, R. R.	41
Salt Range, India	9, 16
<i>Scacchinella</i>	11
Schist, various mica, Toodyay district	97
Schmidt, H.	11
Schnchert, C.	4, 10, 13, 29
Serpentire, Toodyay district	128
Serpentine, analysis	128
Sillimanite, occurrence in Toodyay district	98, 129
Soils of Western Australia	xxix.
Sowerby, J.	30
<i>Streptorhynchus liliuigui</i>	22
Sphenopterid fossils	203
<i>Strophalosia</i>	9, 12, 32, 37
<i>Strophalosia</i> cf. <i>beecheri</i>	41
<i>Strophalosia clarkei</i>	39, 41, 42, 45, 50
<i>Strophalosia complectens</i>	56
<i>Strophalosia etheridgei</i> , sp. nov.	7, 41, 43, 52
<i>Strophalosia fragilis</i>	24, 39
<i>Strophalosia gerardi</i>	41, 43, 45, 47
<i>Strophalosia</i> cf. <i>gerardi</i>	46
<i>Strophalosia gigas</i>	34
<i>Strophalosia horrescens</i>	34, 39
<i>Strophalosia jukesii</i>	38, 47, 50
<i>Strophalosia kimberleyensis</i> , sp. nov.	7, 38, 41, 47, 50
<i>Strophalosia lamellosa</i> var. <i>humbletonensis</i>	38, 39
<i>Strophalosia multispinifera</i> , sp. nov.	50
<i>Strophalosia rarispina</i>	52
<i>Strophalosia tenuispina</i>	51, 52
<i>Strophalosia</i> sp. A.	51
<i>Strophalsiella</i>	40
<i>Strophalosina</i>	35, 36, 40
<i>Strophalosinae</i>	2, 9, 12, 53
<i>Strophomena</i>	9
Sutton, A. H.	11, 12
Spinifex pindan	162
<i>Spirifer marcoui</i>	56
<i>Taeniopterus elongata</i>	201
<i>Taeniopterus caruthersi</i>	203
<i>Taeniopterus spatulata</i>	203
<i>Taeniothaerus</i>	27
<i>Taeniothaerus subquadratus</i>	4, 7, 27, 28, 38
Talbot's Cairn	47
Taynan series	16
<i>Teguliferina</i>	11
<i>Thinnfeldia</i>	201
<i>Thinnfeldia tabragarensis</i>	203
Thomas, J.	31
Tilligary, N.S.W.	21
<i>Tillyardembia</i>	139
Timor	16, 26
Toodyay, geology and petrology of district of	83
<i>Triodia pungens</i> , Ecological succession observed during regeneration after burning	149, 154
<i>Triodia pungens</i> , Effect of burning on	149
<i>Triodia pungens</i> , regeneration of	152
Tschernyschew, T. H.	23
Upper Palaeozoic Bryozoa from Western Australia	187
Vegetation of Western Australia, The	xl.

	Page
Waagen, L.	10, 12, 17, 18, 19, 25, 26, 52
<i>Waagenoconcha</i> ....	... ... ... ... ... ... ... 7, 25
<i>Waagenoconcha imperfecta</i> ....	... ... ... ... ... ... ... 25
<i>Waagenoconcha vagans</i> ....	... ... ... ... ... ... ... 26
Waltharrie Pool ....	... ... ... ... ... ... ... 41
Wandagee and Noonanbah Series (Permian) of Western Australia, Bryozoa from	165
Wandagee Station ....	... ... ... ... ... ... ... 31, 36, 43, 47, 54
Weller, S. ....	... ... ... ... ... ... ... 42
Western Australia. The Vegetation of	... ... ... ... ... ... ... xl.
Whitehouse, F. W. ....	... ... ... ... ... ... ... 27
<i>Winnemia</i> ....	... ... ... ... ... ... ... 22
Winning Station ....	... ... ... ... ... ... ... 24
<i>Wyatkina</i> ....	... ... ... ... ... ... ... 35, 36
Wyndham Gap ....	... ... ... ... ... ... ... 18
<i>Wyndhamia</i> ....	... ... ... ... ... ... ... 5, 40
Yetar Spring ...	... ... ... ... ... ... ... ... 79

